Mr. R. W. Taylor

C69-1868

[redacted]

CLASSIFICATION CHANGE

To UNCLASSIFIED

By authority of GDS - EO 11652

Changed by [illegible] Date 12/31/72

Classified Document Master Control Station, NASA Scientific and Technical Information Facility

GEMINI ABORT SIMULATION STUDY

PROGRAM NO. 2 (U)

NASA CONTRACT NO. NAS 9-712

REPORT NO. 00.100

NOVEMBER 1962

[redacted]

Prepared by:

W. B. Cassidy
Project Engineer

W. B. Luton
Supervisor, Simulator

Approved by:

C. F. Gell, M.D. D.S.C.
Manager, Life Sciences

V. G. Polovkas
R & D Programs

[redacted]

[redacted]

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

1.0 SUMMARY

The second Gemini Launch Simulation confirmed the over-all adequancy of the spacecraft displays to portray critical launch vehicle malfunctions. The program showed that experienced pilots with only two or three days familiarization were able to analyze and react correctly to a wide variation of malfunction situations.

2.0 INTRODUCTION

To verify the feasibility and desirability of using manual escape in the Gemini System, Vought's Manned Aerospace Flight Simulator was utilized to: (1) evaluate the adequacy of the Gemini Launch Vehicle status display group, (2) evaluate the pilots ability to monitor and interpret contingency information presented on the launch vehicle display group and determine if corrective action or mission termination was required, and (3) to further ascertain his ability to perform this action within the time required to save the mission or to execute a successful escape.

This document is a technical report on the results of the simulation program. Included is a description of the program, the simulation facility, and the manner in which it was mechanized. Pertinent test data is tabulated and results of the tests are discussed in detail. Conclusions and recommendations are submitted.

The basic test data, subjects' comments, randomization schedules, and supporting analyses are not part of this document, but are available and may be obtained upon request from the study contractor.

2.1 BACKGROUND

The Mercury automatic abort and sequencing systems involved difficult and extensive development programs. Mercury experience includes several unpredicted malfunctions that occurred during unmanned flights confirming that many of the possible failure modes were not anticipated, and would not therefore be considered in the design of an automatic abort system.

Two of the three manned Mercury Atlas flights involved events that might have triggered an unnecessary abort. On MA-7, one hydraulic pressure sensor line froze. The redundant sensor line was also exposed to possible freezing, and if it had been triggered, the mission would have been lost. On MA-8, an abnormal, but safe, roll rate very nearly aborted the mission. In such cases, a pilot with control of abort initiation improves the probability of mission success because he would terminate the mission only if a real catastrophe were imminent.

If it can be shown that a pilot, using appropriate displays, is capable of evaluating an emergency correctly and that he can abort successfully in time critical situations, then manual abort is feasible. If it can be shown that the pilot can perform this function more reliably than it can be accomplished by an automatic system, then manual abort is desirable. Advantages of a manual abort system are:

1. The crew would have the opportunity to evaluate unexpected emergencies where a totally automatic system would likely respond incorrectly, if at all.

2. In the absence of pre-set abort thresholds, the crew could possibly complete the mission even though all systems did not function perfectly.

3. The spacecraft/booster malfunction detection system and over-all sequencing system is simplified.

4. For non-critical situations, abort can be accomplished during a phase of the flight where risk is minimized. Aborts at maximum q would thus possibly be avoided.

5. The crew would have a more secure and confident attitude, knowing their own decision will govern the success or failure of the mission.

6. Manually initiated escape is an aircraft proven technique that has been traditionally accepted by pilots and used effectively for more than a decade.

The primary concern with a manual system stems from the possibility of pilot error. Astronauts, are, of course, highly experienced test pilots, and intensive training will be utilized to reduce the possibility of error to an absolute minimum.

2.2 OBJECTIVE AND SCOPE OF THE PROGRAM

The main objective of the experiment was to test the ability of the pilot to read and interpret displays of contingency information and make the proper decision in the necessary time interval; this time interval varied in length depending upon the particular malfunction.

Latest malfunction and failure information provided by Martin and NASA was used to determine a schedule of situations to simulate. The scope of this program included the following:

1. Loss of first stage engine thrust.
2. Staging failures and early staging.
3. Pressure loss in fuel and oxidizer tanks.
4. Guidance failures.
5. DC power failure.
6. Instrument and light malfunctions.

2.3 CORRELATION BETWEEN GEMINI ABORT PROGRAM NO. 1 AND NO. 2

The No. 2 abort program was designed in a manner very similar to the first program reported in Reference 1. The most significant changes were: the instrument panel was replaced with a duplication of the pilot-commander's launch vehicle display panel; and, numerous additions and deletions were made to the list of abort situations which were mechanized. The computer time functions were altered to accommodate the panel displays and warning lights, and the tank pressure functions were programmed so that decay began at T-3.0 to simulate the loss incurred before lift-off.

The seat vibrator was eliminated from the cockpit during the No. 2 abort program. Its function (20 cps at 0.1 g) was accomplished by vibrating the entire gondola by means of its pitch gimbal.

2.4 DESCRIPTION OF TEST FACILITY

The facility in which the experiment was conducted consisted of a moving base cockpit simulator with vibration and noise capabilities, (Figures 1 and 2) and a combination analog-digital computer. The moving base cockpit is mounted inside a 20 foot diameter sphere with a high fidelity sound system to simulate rocket noise. Perturbations in pitch, roll and yaw were applied to the moving base. Booster axial accelerations were represented by the gross pitch motion of the gondola, which by shifting the pilot's weight onto and off his back gave the sensation of longitudinal acceleration. Since the simulation was of open loop type, the digital computer was conveniently used to generate the time variant signals for the moving base and the instrument panel. The analog portion of the computer was used chiefly to drive the simulator components and to generate the various vibrations. A tape recorder was used for noise generation.

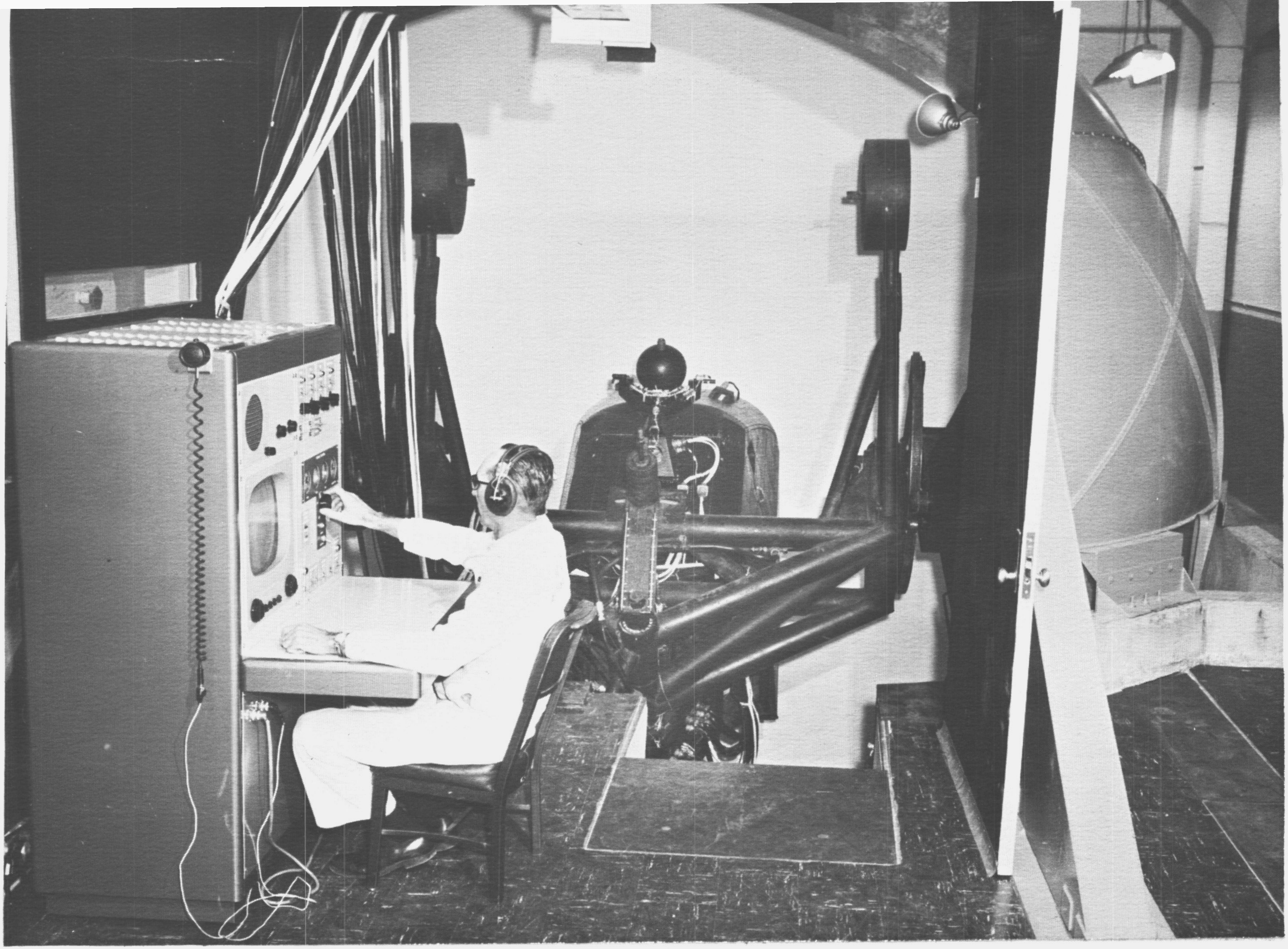

FIGURE 1 - GENERAL VIEW OF MANNED AEROSPACE FLIGHT SIMULATOR

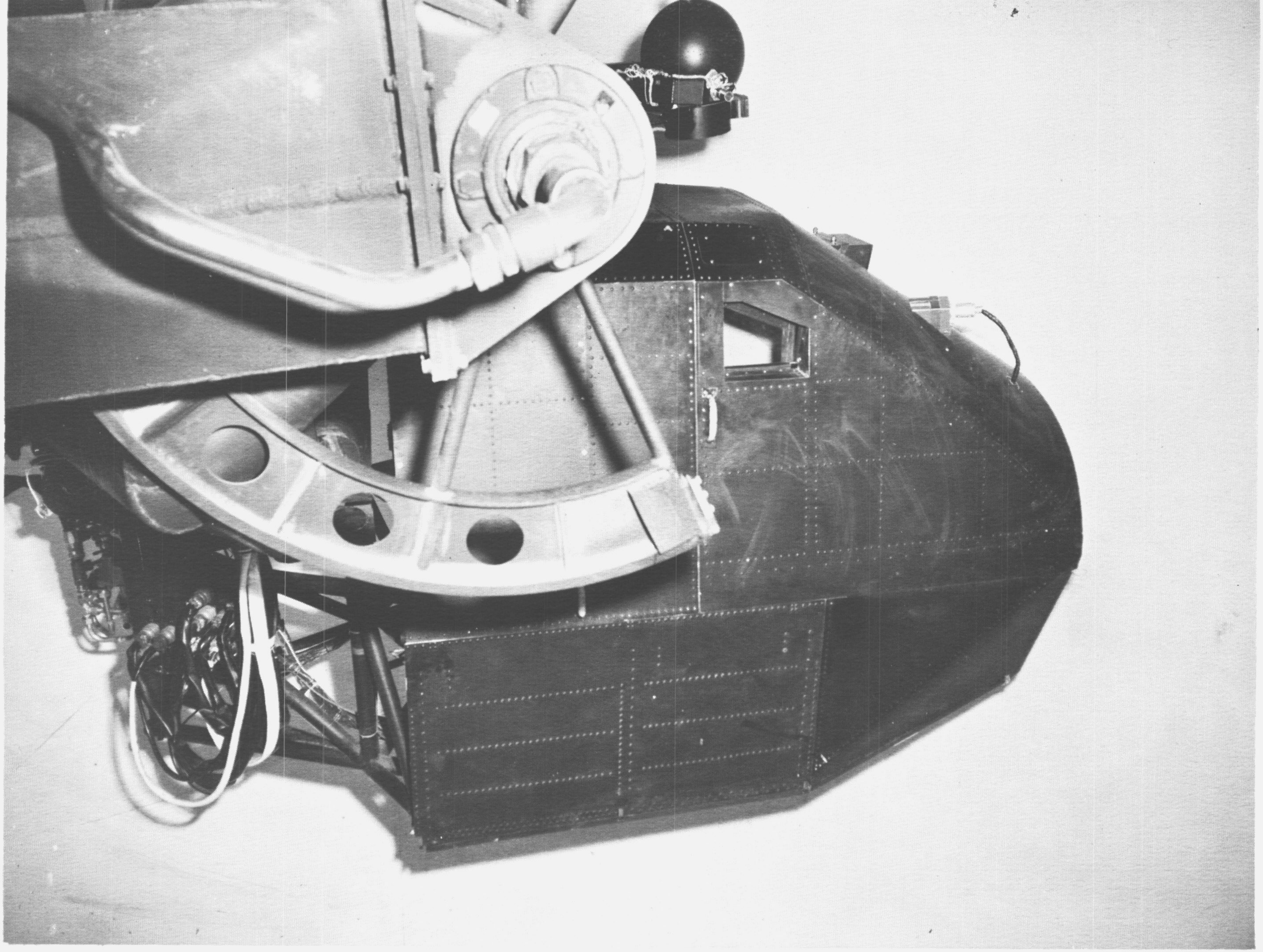

FIGURE 2 - GONDOLA - MANNED AEROSPACE FLIGHT SIMULATOR

3.0 METHOD

3.1 TITAN II MALFUNCTIONS

In contrast to the first Gemini Abort Study Program where 23 runs representing 8 major types of malfunctions were presented to six pilots, the second program had 51 runs representing 9 major types of malfunctions presented to two pilots. The selected malfunctions were based on the failure data for the Titan II booster as presented in References 2, 3 and 4. Stage one and two tank pressure excursions were determined from information contained in Reference 5. NASA and Vought technical personnel established the number of runs for each type of malfunction and the time that the malfunctions were to begin. This selection was based on the criticalness of the malfunctions with respect to anticipated pilot difficulty in detecting and evaluating the cues and the required response time for taking corrective action. Thirty-two of the fifty-one malfunction runs were cases where the malfunction occurred ten seconds or less from either lift-off or staging. In each case, the required response time was based on the time from malfunction onset until the time when a catastrophic failure occurred, minus the system sequencing time. The sequencing times of the systems used in this program were zero (.00) for the secondary guidance switch-over and booster shut-down, .44 seconds for the ejection seat escape system, and 1.05 seconds for the capsule escape system.

In addition to the malfunction runs listed in Table 1, three variations of the normal boost run were simulated. It should be noted that the most difficult runs were selected for use in the simulation program regardless of their probability of occurrence in actual flight.

Table 1 is a list of the malfunction runs simulated and the number of variations of each run as presented to the subjects.

3.2 EXPERIMENTAL DESIGN

The experimental design for the simulation program was prepared so as to present the maximum number of runs to each subject during the time they were available as test subjects. The two subjects selected by NASA were made available for four days of which one day was required for indoctrination and training. Each subject was scheduled for approximately 75 runs - 65 having malfunctions and 10 being normal. Each of the 51 malfunction runs was presented to the subjects at least once and the 14 most difficult runs were presented twice to each subject. The runs were randomly distributed so that the subjects had no way of knowing which problem would be presented next. The runs were presented on the average of one every six minutes for test periods not exceeding three hours. Subjects were rotated and allowed rest periods to avoid fatigue.

<u>TABLE 1</u>

Type and Number of Malfunction
Runs Simulated

Problem	Type of Malfunction	No. of Runs
I-4*	Partial Loss of Thrust - 1 engine (1st stage)	1
II-1, 2	Total Loss of Thrust - 1 engine (1st stage)	2
III-1, 2	Total Loss of Thrust - Both engines (1st stage)	2
V-4, 5, 6, 7 9, 10, 11	Staging Failures	7
VI-13 thru 17, 19 thru 24, 26 thru 46	Tank (fuel and oxidizer) pressure losses	32
VII-1	Adverse Roll	1
VII-3, 4	D.C. Power Failures	2
IX-5, 6, 7	Instrument Malfunction	3
XI-1	Light Failure	1
	Total number of runs	51

* In the interest of consistency, each run is identified in accordance with the numbering system established in the Gemini Abort Program No. 1.

Each subject was scored and evaluated on: (1) his ability to recognize the run as normal or one having a malfunction, (2) his diagnosis of a malfunction, (3) his ability to make the proper decision, and (4) his ability to take the proper action within the allowable time. The results of the runs are discussed in detail in Section 5.0 of this report.

Actuation of the "D" ring for seat escape, the toggle switch for capsule escape, or the toggle switch for changing from primary to secondary guidance, terminated the run by stopping the computer and all mechanized simulator functions. This procedure was incorporated to expedite the program and to provide immediate feedback of information to the subjects. The time of actuation was recorded automatically by the computer flexowriter to the nearest .01 second. When the subject identified the run either verbally or by actuating one of the three devices he would then give his comments regarding the cues leading to this identification along with any other facts he believed to be beneficial in the analysis of the results. The subject was advised immediately if his identification was correct and if his action of aborting or switching to secondary guidance was initiated within the allowable time. If a catastrophe occurred, a red light on the cockpit console was automatically illuminated. Only the experimenter at the control console and the safety monitor could communicate with the subject. All communications were restricted during the formal test-runs. Two closed circuit television screens were used to observe the subject being tested.

The experimenter had available at the control console the following:

1. A master switch for initiating and terminating the runs.

2. A series of lights to indicate the lights that were illuminated on the abort panel.

3. A series of lights indicating the various events during the boost phase.

4. An event timer corresponding to the event timer on the abort panel.

5. Computer flexowriter.

6. Lights to indicate the position of the abort handles and secondary guidance switch.

The following basic "ground rules" were established prior to the start of the experimental runs. The subjects were advised of these rules and were given a copy of them to study. Any deviation from these ground rules was considered an error.

Event	Correct Action
Total loss of thrust in both engines	Abort immediately
Any loss of thrust in one engine	Abort on abort light or after 120 seconds and before 139.5 seconds.

Event	Correct Action
No separation	Abort on abort light.
Low 2nd stage thrust	Abort not time critical.
No staging	Abort not time critical.
DC power failure	Switch to secondary guidance (unless already switched by automatic sensor).
Instrument failure	Do not abort.
Engine light illuminates	Do not abort unless there are secondary cues.
Early staging	Do not abort.
Guidance failure	Switch to secondary guidance immediately.

In addition to these ground rules, the pilots were instructed not to abort on single cues. Furthermore, they were advised that there were no double failure type runs of the malfunction sensors or the basic vehicle systems in the simulation program.

3.3 SUBJECTS

The two pilots participating in the program were Mercury Astronauts and had participated as subjects in the first Gemini Abort Simulation Study. Both pilots had a thorough knowledge of the Gemini launch vehicle, extensive aircraft flight test experience and were very familiar with the Vought Astronautics simulator.

3.4 EXPERIMENTAL PROCEDURE

Two weeks before the subjects participated in the simulation test program, they were furnished pre-experimental study material, reference 6. Appendix A contains portions of this material.

Other material forwarded included:

1. General description of the program.
2. Description and pictures of the launch vehicle instrument panel.
3. Description of the normal boost.
4. Description of the malfunctions.
5. A series of curves supporting the descriptions of (3) and (4).

When the two Astronaut subjects selected by NASA arrived at Vought, they received approximately one hour of review covering the Gemini abort panel, description of malfunction and normal runs, experimental procedure, simulation ground rules, and the operation of the abort mechanisms and secondary guidance switch. Details of the specific runs used in the test program were withheld from the subjects.

Following the verbal instruction session, the subjects were introduced to the simulator for a review of the panel, mechanizations, etc. Each subject was then given a normal boost run with the gondola in a locked position and an instructor pilot standing on the side pointing out the sequence of events and advising the subject on the procedure for monitoring the instrument panel. The subjects were given an opportunity to review the instructions and ask questions. The pre-experimental training was identical for both subjects.

The gondola was unlocked and the subjects were given a selected group of 19 training runs. These runs were X-1, I-4, II-2, III-2, V-4, V-7, V-9, V-16, VI-19, VI-27, VI-28, VI-36, VI-40, VI-42, VI-44, VIII-1, IX-5, VII-4, and a repeat of X-1. Prior to each run the experimenter explained in detail the type of run and the cues that would be prevalent. The subjects were encouraged to ask questions and clarify any problem areas. At the end of the training runs, they were afforded the opportunity to re-run any of the training series.

The experimental runs were started at this time. The procedure for initiating each run was the same and was as follows:

1. The subject was advised that the run was ready to proceed.

2. Subject was asked to confirm that the event timer was reset to zero and all switches were returned to normal.

3. Simulator safety control station was checked for "go" status.

4. Subject in cockpit was checked for "go" status.

5. The experimenter initiated his countdown at T-10 and at T-4 he actuated the master switch which started the program in the computer at T-3. A description of this program is presented in the Section 4.0 of this report.

Basal response time measurements were made on each subject somewhere between runs 30 and 40. The measurements were made following a "break" period. Basal response times were measured for operation of the seat abort handle, capsule abort switch, and secondary guidance switch. In each case twenty measurements were taken by having the subject respond to the illumination of the abort light on the instrument panel. Subjects were asked to keep their hands in the normal operating position while waiting for the light. The interlight interval was variable. The abort light switch-on and recording of the exact time of actuation were programmed in the computer and were completely automatic. Table 2 is the results of the basal response time measurements.

TABLE 2

Basal Response Times (Average of 20 Measurements)

Time in Seconds

Subject	Seat Abort	Booster Shut-Down and Capsule Abort	Secondary Guid.
A	.40	.76	.71
B	.38	.78	.70

3.5 FILM REPORT

A technical film was produced to supplement this report. The colored sound track film depicts the entire Gemini Abort Simulation program. including scenes inside the gondola of the Gemini abort launch vehicle panel during typical runs. Samples of every type run are shown. Copies of this film were delivered to NASA as part of the contract requirements.

4.0 MECHANIZATION OF THE SIMULATION

The hardware components for the simulation consisted of a combination analog-digital computer and a moving base cockpit simulator Figure 1 and Figure 2. The moving base generated the motions shown in Figure 5, the pitch, roll, and yaw transients occurring as a result of programmed malfunctions. Contained in the cockpit simulator were the launch vehicle, instrument panel, a "D" ring seat eject handle, and an emergency booster shutdown - capsule abort switch. A secondary guidance switch, to be accuated in the event of a guidance failure, was mounted adjacent to the instrument panel. High fidelity noise reproducing equipment was used to simulate engine noise (Figure 6).

Following is a description of the instrument panel, the computer-flight simulator arrangement, the standard boost trajectory and the malfunction runs.

4.1 LAUNCH VEHICLE INSTRUMENT PANEL

The instrument panel shown in Figure 3 and 4 is a replica of the one in the Gemini pilot-commander station. The launch vehicle display group portion of the panel is identified on Figure 3 by the marked-off area. All of the instruments and lights within this area were active for the simulation program and the ones outside this area were static displays.

The following is a description of the launch vehicle displays:

1. Attitude Display - a three axis attitude ball was used which also contained two command bars used as rate indicators for pitch and yaw. Scaling on these bars was arbitrarily established so that maximum deflections were equal to 15 degrees per second.

2. Tank Pressure Displays - tank pressure levels were displayed by two separate vertical indicating instruments.* each of which indicated both fuel tank and oxidizer tank pressures for a separate stage. Two indicators were used for each of the four pressure measurements so that a failure of one of the indicators could be distinguished from an actual tank pressure loss where both needles would simultaneously indicate pressure drop. Both instruments have markings showing the minimum tank pressure for engine operation (cross hatched area), and the stage I instrument shows the minimum structural pressures required at 20, 40 and 60 seconds. The stage two instrument had a marking at 40 psia indicating the minimum allowable stage II fuel tank pressure for safe staging.

3. Longitudinal Acceleration - this dial, graduated in g units, displayed the amount of axial acceleration programmed to be acting on the vehicle during boost.

4. DC power - DC power failure was indicated by an immediate drop of the four left hand needles on all four of the pressure measurements (four of the eight needles would "bottom").

*Manufactured by Lear, Inc., Model Number 2700-A, Serial Numbers NAS 62-IM 62-21 and NAS 62-IM 62-22

5. Counter - the event timer was programmed to indicate elapsed time in seconds. Pulsations of this event timer were audible to the subject.

6. Attitude Rate Warning Light - this light indicated pitch and yaw rates equal to or greater than 4 deg/sec.

7. Engine Chamber Pressure Lights 1 and 2 - each light flashed on when the respective engine chamber pressure was below 65% of maximum thrust. The exception was that the engine 1 light stayed off during staging since it was deactivated at 139.5 seconds.

8. Stage Initiation Light - this light flashed on at 148.3 seconds and indicated the start of the staging cycle. Physical separation of the two stages would cause the stage light to go off.

9. Guidance System Light - this light indicated operation of the secondary guidance system.

10. Abort Light - the purpose of this indicator was to transmit to the pilot an abort command from the ground.

11. Catastrophe Light - this light was mounted on the side panel along with the secondary guidance switch and automatically indicated a catastrophe if one occurred. (This light is not part of the launch vehicle panel, but was used to provide feedback information to the subjects.)

The instruments on the panel had no internal illumination, except the attitude ball, and hence depended on cockpit lighting. The engine 2, stage and guidance lights were amber and the remainder of the warning lights were red.

4.2 MANNED AEROSPACE FLIGHT SIMULATOR - COMPUTER ARRANGEMENT

The following is a description of the computer flight simulator set-up, the equipment used, cockpit motions, noise generation equipment, etc.

Drive mechanisms for instruments and warning lights-longitudinal acceleration and the three axis attitude ball were synchro driven. This was accomplished by appropriate digital to analog conversion of the time variant driving functions.

Cockpit Motions - three degrees of freedom were available in the moving base cockpit: they were angular motions in pitch, roll and yaw and had adequate displacement and washout capabilities to simulate small perturbations of the normal vehicle accelerations. In addition a gross pitch rotation of $\mp 100^{\circ}$ from the horizontal permitted a partial simulation of the direction and magnitude (up to 1g) of axial accelerations. The cockpit motions were accomplished with hydraulic servos driven by analog signals.

Figure 5, which was patterned after an Atlas MA-2 flight spectrum supplied by NASA as a guide inasmuch as Titan II information was not available, illustrates the oscillations vs. time which were applied during the standard boost run. Additional accelerations as required for simulating those motions relating to vehicle malfunctions were applied to the pitch and yaw parameters. Roll accelerations associated with the malfunctions were considered too small to warrant simulation.

In order to produce the sensation of the pilot lying on his back ready for boost, the gross pitch was rotated up to approximately 57^{o} from the horizontal for the launch position. At lift-off, it was rotated from 57^{o} to 75^{o} within one second producing the sensation of "eye balls in" type thrust on the pilot. The cockpit then continued to rotate up to 90^{o} representing the first few seconds of acceleration after launch. With an abrupt change in axial acceleration (staging, partial loss of thrust, etc.) it rotated downward for reducing thrust and upward for increasing thrust.

Noise Generation - the combination of engine and aerodynamic noise was simulated by a high fidelity speaker system located in the dome surrounding the cockpit. Most of the noise contained frequencies between 50 and 2000 cps with the low frequency noise ranging from 100 to 150 cps. The maximum intensity level inside the closed cockpit near the pilot's head was 104 db which occurred at maximum q. Figure 6 shows the history of noise level vs time for the standard boost where 104 db occurred at maximum dynamic pressure. Corresponding deviations were programmed as applicable for each malfunction.

4.3 PROGRAMMING

The standard boost run is outlined by Table A-1 and its supporting figures. Standard vibration and noise programs are illustrated in Figures 5 and 6 respectively.

4.3.1 Malfunction Runs

The malfunction runs are divided into nine categories. The following is a brief description of the assumptions employed. A comprehensive outline of each run is presented in Table A-1 and its supporting figures.

1. Partial Loss of Thrust - One Engine (1st Stage) - In a single run (I-4), the assumption was made that the thrust in one engine drops to 65 percent after one second and levels off at 60 percent. Critical times and available cues are outlined in the table on page 30.

2. Total Loss of Thrust - One Engine (1st Stage) - The two runs in this category were programmed to simulate a total loss of thrust of one of the first stage engines. The abort light flahsed on at the simulated peak altitude of the system attained subsequent to the malfunction. Critical times and available cues are listed in the tables on pages 31 and 32.

3. Total Loss of Thrust - Both 1st Stage Engines - This category represented a total loss of booster thrust shortly after lift-off in one run and at maximum dynamic pressure in a second run. The early malfunction required a fast seat eject to prevent hitting the ground with a closed parachute;

the later run also required a fast abort since the booster would quickly break up under the given conditions. See pages 33 and 34 for the critical times and cues.

4. Staging Failures - Seven malfunctions were programmed in this group. Run V-4 was concerned with the failure of the stages to separate because the explosive bolts were not detonated, this condition being conducive to a fire caused by prolonged burning in the hole. Run V-10 was identical to V-4 except that the abort light came on at T+149.7.

Run V-5 was designed around an excess stage I thrust tail-off at staging which could cause a mild explosion due to a lengthy fire in the hole circumstance. The assumption was made that the stage II engine thrust was not sufficient to cause separation before the catastrophe occurred. Again, run V-11 was identical to V-5 except that the abort light came on at T+149.7.

The case where the stages failed to separate because the second stage engine did not start was mechanized for run V-6. Run V-7 was mechanized under the assumption that the second stage engine failed to develop full thrust. Run V-9 was programmed with the assumption that the stage initiation arming circuit was not energized as required at T+139.5. Critical times and cues for the staging malfunctions are listed in the tables on pages 35, 37, 38, 39 and 40.

5. Fuel and Oxidizer Tank Pressure Loss - The 32 pressure loss malfunctions were designed such that the only indication given the test subject was a subnormal pressure level displayed by the pressure instruments. In all cases, the test subject was concerned with either minimum tank pressures for structural purposes or minimum pressures for engine operation. Critical times are listed in the tables on pages 41, 43, 44 and 46.

6. Adverse Roll - Run VII-1 was mechanized to simulate a vehicle roll (heading on the attitude indicator) in the wrong direction at T+5.0.

7. DC Power Failure - A failure of the instrument power system was simulated for the two runs in this classification. Pertinent data is given in the tables on pages 48 and 49.

8. Instrument Malfunctions - Three non-abort runs were mechanized for the case where one of two identical tank pressure indicators failed. Additional information is given on pages 50 and 51.

9. Light Failure - During run XI-1 the engine 1 light failed on at T+2.3. There were no secondary indications of thrust loss, therefore an abort was not required.

4.3.2 Deviation Runs

Two additional non-abort runs were programmed with slight deviations from the standard. Run X-2 was instrumented to simulate an eight second early stage initiation; X-3 was a normal run except that the engine 1 light was not disabled at T+139.5.

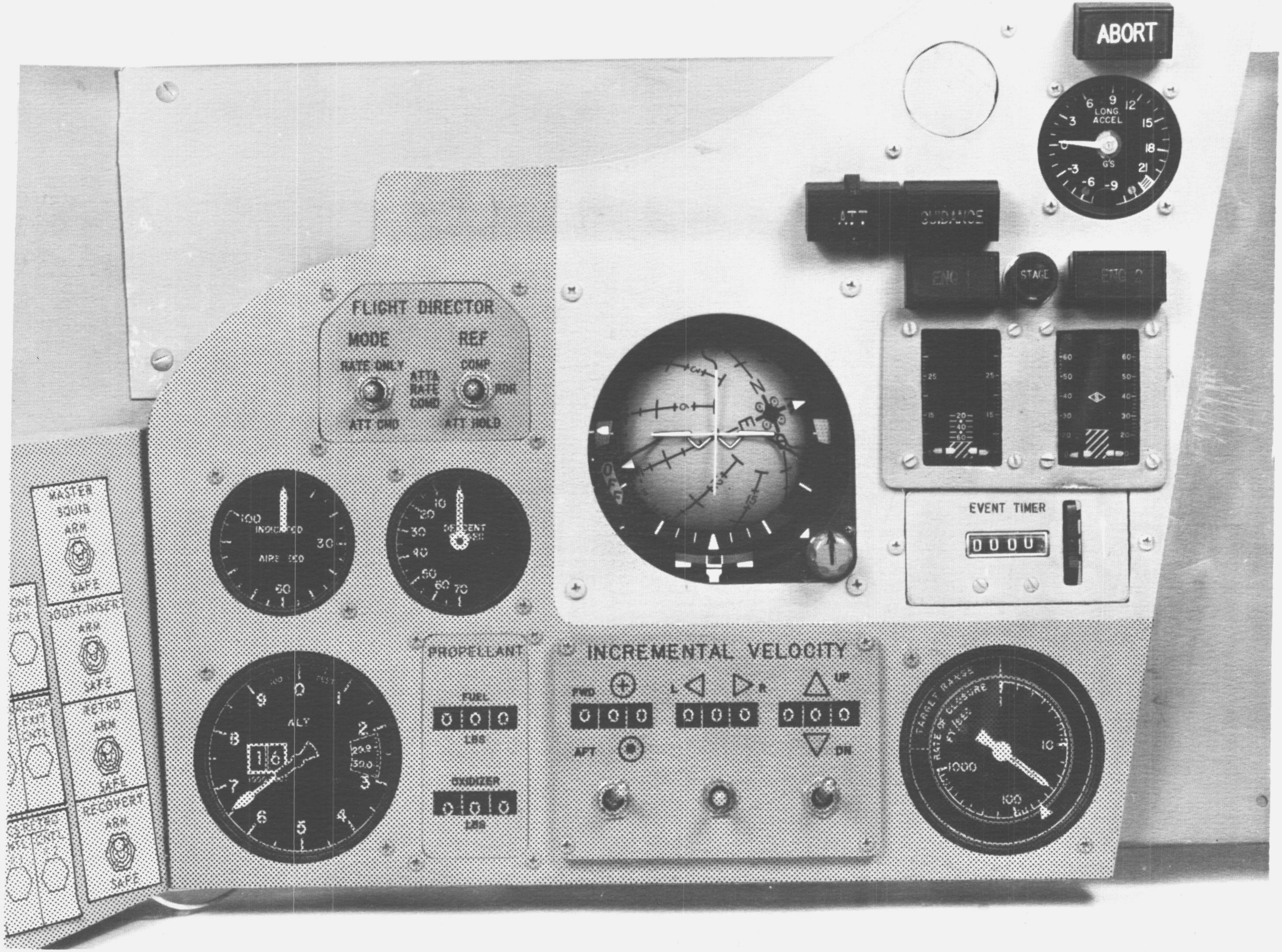

FIGURE 3 - LAUNCH VEHICLE DISPLAY PANEL

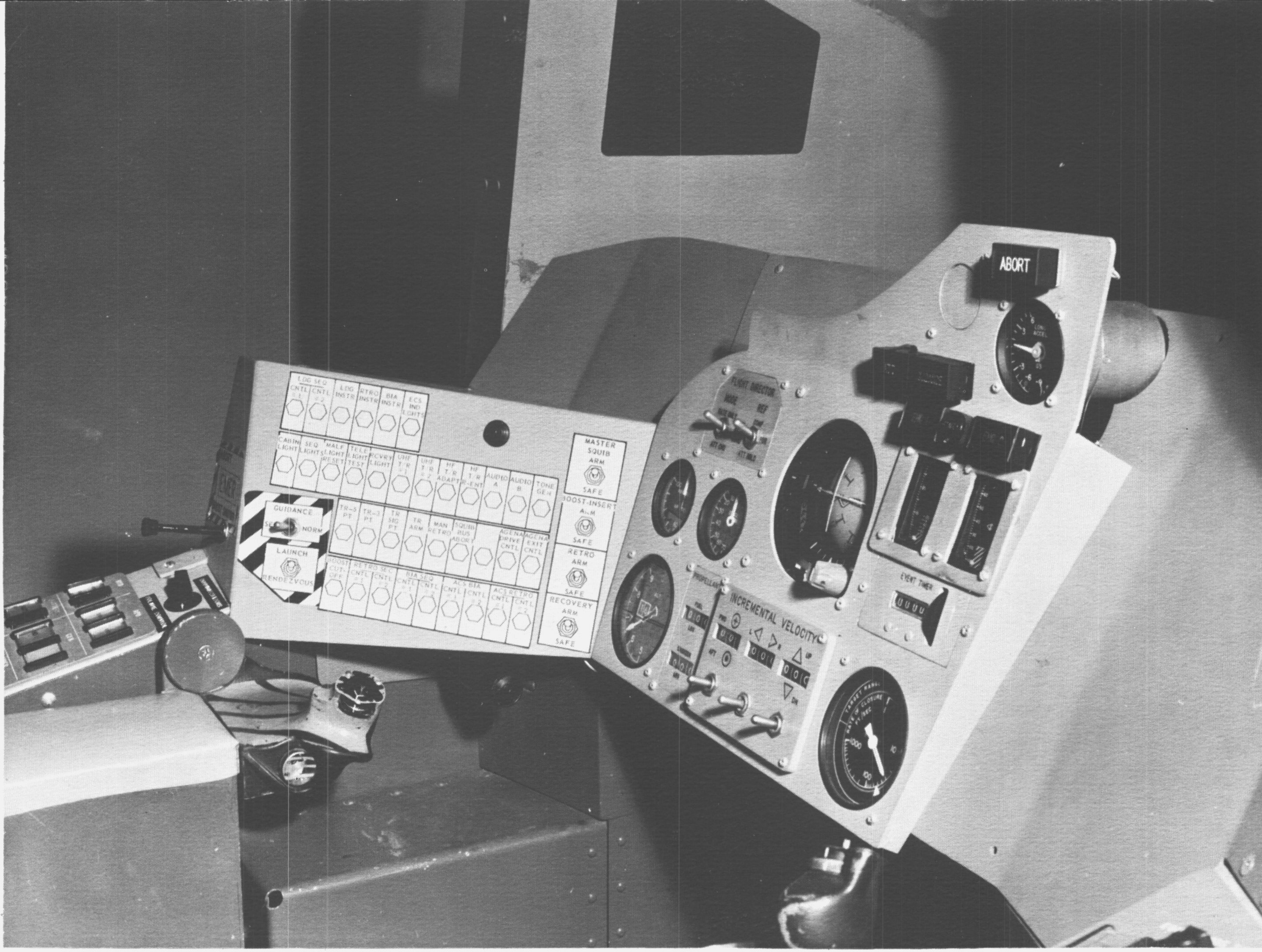

FIGURE 4 - LAUNCH VEHICLE DISPLAY PANEL INSTALLED IN GONDOLA

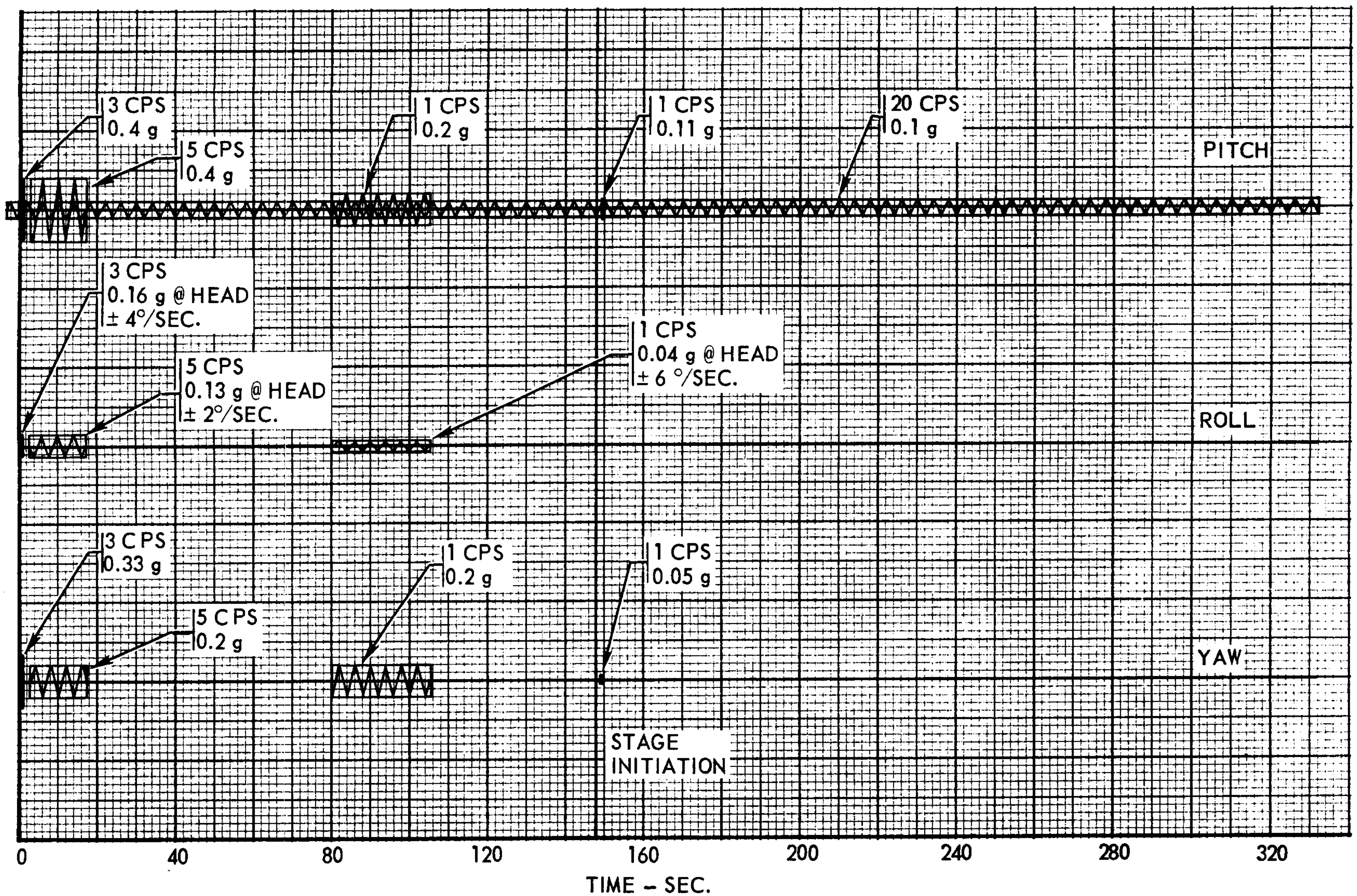

FIGURE 5 VIBRATION PROGRAM

FIGURE 6 NOISE PROGRAM

5.0 RESULTS AND DISCUSSION

Table 3 is a compilation of the test results for each of the two subjects. Included in the table are the required response times, actual response times, delta between response time and actual time, and tabulation of the pilot decision results. Discussion of the individual runs are presented in the following pages as are the conclusions and recommendations.

The findings of this experiment are valid and conclusive, but there were certain test conditions which must be considered when interpreting the results of the program. These conditions are as follows:

1. The subjects had a limited indoctrination and training period.

2. The tests were conducted in a period of three days.

3. The tank pressure instruments were prototypes and had certain deficiencies such as the tendency of one needle to stick, lack of linearity and questionable display markings.

Information regarding the effects of a malfunction in the Titan II missile, as they pertain to the analysis of the rest results, were obtained by Vought during a series of meetings with members of the Integrated Gemini Abort Committee. These meetings were held subsequent to the simulator tests, but prior to the evaluation and reporting of the results.

TABLE 3

Test Results

Prob. No.	Type of Malfunction	Req'd. Action	Subject	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action On Time	Action Late	Correct Decision
I-4	Partial loss of thrust - 1 eng.	NAR	A	T+ 6.86					*
			A						Yes
			B						Yes
			B						Yes
II-1	Total loss of thrust 1 engine	Seat Abort	A	T+ 5.77	3.77	2.26		1.51	Yes
			B	T+ 4.98	2.98	2.26		0.72	Yes
II-2	Total loss of thrust 1 engine	Seat Abort	A	T+16.11	1.11	34.56	33.45		Yes
			B	T+35.64	20.64	34.56	13.92		Yes
III-1	Total loss of thrust Both engines	Seat Abort	A	T+ 5.40	1.40	1.26		0.14	Yes
			A	T+ 5.25	1.25	1.26	0.01		Yes
			B	T+ 4.39	0.39	1.26	0.87		Yes
			B	T+ 4.93	0.93	1.26	0.33		Yes
III-2	Total loss of thrust Both engines	Seat Abort	A	T+70.94	0.94	1.46	0.52		Yes
			A	T+70.89	0.89	1.46	0.57		Yes
			B	T+70.89	0.89	1.46	0.57		Yes
			B	T+71.15	1.15	1.46	0.31		Yes

* See Page 30

TABLE 3 - Test Results (continued)

Prob. No.	Type of Malfunction	Req'd. Action	Subject	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action On Time	Action Late	Correct Decision
V-4	No fire bolts signal	Stage II Shut-down	A	T+150.06	1.76	2.17	0.41		Yes
			B	T+150.43	2.13	2.17	0.04		Yes
V-5	Excess Stage I tailoff	Stage II Shutdwn	A	T+150.22	1.92	2.17	0.25		Yes
			B	T+150.48	2.18	2.17		0.01	Yes
V-6	Stage II fails to bootstrap - no thrust	Capsule Sep.	A	T+150.74	2.44				Yes
			B	T+158.26	9.96				Yes
V-7	Stage II fails to bootstrap - low thrust	Capsule Sep.	A	T+165.62	17.32				Yes
			A	T+175.49	27.19				Yes
			B	T+205.31	57.01				Yes
			B	T+150.38	2.08				Yes
V-9	No staging	Capsule Sep.	A	T+153.25	13.75		5.70		Yes
			B	T+173.09	33.59				Yes
V-10	No fire bolts signal	Stage II Shutdwn	A	T+151.32	3.02	2.17		0.85	Yes
			A	T+150.43	2.13	2.17	0.04		Yes
			B	T+150.48	2.18	2.17		0.01	Yes
			B	T+150.22	1.92	2.17	0.25		Yes

TABLE 3 - Test Results (continued)

Prob. No.	Type of Malfunction	Req'd. Action	Subject	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action On Time	Action Late	Correct Decision
V-11	Excess Stage I tail-off	Stage II Shutdwn	A	T+150.22	1.92	2.17	0.25		Yes
			A	T+150.27	1.97	2.17	0.20		Yes
			B	T+150.69	2.39	2.17		0.22	Yes
			B	T+150.28	2.08	2.17	0.09		Yes
VI-13	Tank pressure loss - Stage I fuel	Seat Abort	A	T+ 1.43	1.43	1.06		0.37	Yes
			A	T+ 1.59	1.59	1.06		0.53	Yes
			B	T+ 1.33	1.33	1.06		0.27	Yes
			B	T+ 2.06	2.06	1.06		1.0	Yes
VI-14	Tank pressure loss-Stage I fuel	Seat Abort	A	T+ 4.67	4.67	4.66		0.01	Yes
			B	T+ 5.09	5.09	4.66		0.43	Yes
VI-15	Tank pressure loss - Stage I fuel	Seat Abort	A	T+ 7.39	2.39	1.76		0.63	Yes
			A	T+ 6.86	1.86	1.76		0.10	Yes
			B	T+ 7.28	2.28	1.76		0.52	Yes
			B	T+ 7.07	2.07	1.76		0.31	Yes
VI-16	Tank pressure loss - Stage I fuel	Seat Abort	A	T+ 9.11	4.11	4.76	0.65		Yes
			B	T+ 10.57	5.57	4.76		0.81	Yes
VI-17	Tank pressure loss - Stage I fuel	Seat Abort	A	T+ 14.75	4.75	8.06	3.31		Yes
			B	T+ 15.17	5.17	8.06	2.89		Yes

TABLE 3 - Test Results (continued)

Prob. No.	Type of Malfunction	Req'd. Action	Subject	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action		Correct Decision
							On Time	Late	
VI-19	Tank pressure loss - Stage I fuel	Seat Abort	A	T+ 30.68	5.68	7.06	1.38		Yes
			B	T+ 31.57	6.57	7.06	0.49		Yes
VI-20	Tank pressure loss - Stage I fuel	NAR	A						Yes
			B						Yes
VI-21	Tank pressure loss - Stage I fuel	Capsule Sep.	A	T+113.04	33.04	43.95	10.91		Yes
			B	T+117.79	37.79	43.95	6.16		Yes
VI-22	Tank pressure loss - Stage I fuel	NAR	A						Yes
			B						Yes
VI-23	Tank pressure loss - Stage I fuel	NAR	A						Yes
			B						Yes
VI-24	Tank pressure loss - Stage I oxz.	Seat Abort	A	T+ 3.68	3.68	3.86	0.18		Yes
			B	T+ 3.99	3.99	3.86		0.13	Yes
VI-26	Tank pressure loss - Stage I oxz.	Seat Abort	A	T+ 8.33	3.33	3.26		0.07	Yes
			A	T+ 8.12	3.12	3.26	0.14		Yes
			B	T+ 8.60	3.60	3.26		0.34	Yes
			B	T+ 8.64	3.64	3.26		0.38	Yes
VI-27	Tank pressure loss - Stage I oxz.	Seat Abort	A	T+ 13.24	8.24	8.86	0.62		Yes
			B	T+ 14.59	9.59	8.86		0.73	Yes

TABLE 3 - Test Results (continued)

Prob. No.	Type of Malfunction	Req'd. Action	Subj.	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action		Correct Decision
							On Time	Late	
VI-28	Tank pressure loss-Stage I oxidizer	Seat Abort	A	T+ 14.33	4.33	4.16		0.17	Yes
			A	T+ 14.38	4.38	4.16		0.22	Yes
			B	T+ 14.91	4.91	4.16		0.75	Yes
			B	T+ 14.38	4.38	4.16		0.22	Yes
VI-29	Tank pressure loss-Stage I oxidizer	Seat Abort	A	T+ 23.70	8.70	13.26	4.56		Yes
			B	T+ 26.13	11.13	13.26	2.13		Yes
VI-30	Tank pressure loss-Stage I oxidizer	NAR	A						Yes
			B						Yes
VI-31	Tank pressure loss-Stage I oxidizer	NAR	A						Yes
			B						Yes
VI-32	Tank pressure loss-Stage I oxidizer	NAR	A						Yes
			B						Yes
VI-33	Tank pressure loss-Stage I oxidizer	NAR	A						Yes
			B						Yes
VI-34	Tank pressure loss-Stage II fuel	Cap. Sep.	A	T+120.0					Yes
			B	T+120.29					Yes
VI-35	Tank pressure loss-Stage II fuel	Cap. Sep.	A	T+120.62					Yes
			B	T+120.20					Yes
VI-36	Tank pressure loss-Stage II fuel	Cap. Sep.	A	T+120.56					Yes
			B	T+120.40					Yes

TABLE 3 - Test Results (continued)

Prob. No.	Type of Malfunction	Req'd. Action	Subj.	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action On Time	Action Late	Correct Decision
VI-37	Tank pressure loss- Stage II fuel	Cap. Sep.	A	T+151.37	3.07	7.95	4.88		Yes
			B	T+151.26	2.96	7.95	4.99		Yes
VI-38	Tank pressure loss- Stage II fuel	Cap. Sep.	A	T+154.87	1.57	0.45		1.12	Yes
			A	T+154.71	1.41	0.45		0.96	Yes
			B	T+154.87	1.57	0.45		1.12	Yes
			B	T+154.45	1.15	0.45		0.70	Yes
VI-39	Tank pressure loss- Stage II fuel	Cap. Sep.	A	T+170.22	1.92	2.05	0.13		Yes
			A	T+170.85	2.55	2.05		0.50	Yes
			B	T+169.85	1.55	2.05	0.50		Yes
			B	T+169.91	1.61	2.05	0.44		Yes
VI-40	Tank pressure loss- Stage II fuel	Cap. Sep.	A	T+189.54	21.24	43.25	22.01		Yes
			B	T+200.04	31.74	43.25	11.51		Yes
VI-41	Tank pressure loss- Stage II fuel	Cap. Sep.	A	T+310.91	42.61	55.45	12.84		Yes
			B	T+317.13	48.83	55.45	6.62		Yes
VI-42	Tank pressure loss- Stage II oxidizer	Cap. Sep.	A	T+120.56					Yes
			B	T+120.35					Yes
VI-43	Tank pressure loss- Stage II oxidizer	NAR	A						Yes
			B						Yes
VI-44	Tank pressure loss- Stage II oxidizer	NAR	A						Yes
			B						Yes

TABLE 3 - Test Results (continued)

Prob. No.	Type of Malfunction	Req'd Action	Subject	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action		Correct Decision
							On Time	Late	
VI-45	Tank pressure loss-Stage I fuel	NAR	A B						Yes Yes
VI-46	Tank pressure loss-Stage I oxidizer	NAR	A B	T+30.83					No Yes
VII-1	Adverse roll	Guid. Switch-over	A B	T+ 9.79					Yes *
VIII-3	DC power failure	NAR	A B						Yes Yes
VIII-4	DC power failure	Guid. Switch-over	A A B B	T+98.78 T+98.99 T+95.75					Yes Yes No No
IX-5	Instrument mal-function	NAR	A B						Yes Yes
IX-6	Instrument mal-function	NAR	A B						Yes Yes
IX-7	Instrument mal-function	NAR	A B	T+10.52					No Yes

* See Page 47

TABLE 3 - Test Results (continued)

Prob. No.	Type of Malfunction	Req'd. Action	Subject	Pilot Action Compl.	Pilot Response Time	Required Response Time	Action On Time	Action Late	Correct Decision
X-1	Normal boost	NAR	A B	(8 runs) (7 runs)					Yes Yes
X-2	Normal boost - early stage	NAR	A B						Yes Yes
X-3	Normal boost - engine I light not disabled at T+139.5	NAR	A B						Yes Yes
XI-1	Engine I light failure	NAR	A A B B						Yes Yes Yes Yes

Problem I-4 Partial Loss of Thrust One Engine - Stage I

	Time Seconds	Cues Available
Malfunction Begins	T + 5.0	Moderately rapid loss of 20% of axial feel and noise. Slower increase of accel. instr.
	T + 6.0	Engine I light comes on.
	T +120.0	Abort light comes on.
Abort not time critical	T +120 +	

The loss of axial acceleration, the reduction of noise, and the illumination of engine I light provide immediate identification of a loss of thrust. However, it is difficult to determine whether it is total or partial loss of thrust in one engine. This was not important since the ground rule was the same for both.

From Table 3 it can be seen that in 3 of the 4 runs the pilots correctly diagnosed the malfunction and executed the abort at the preferred time. In one case, the pilot aborted immediately upon detecting a loss of thrust which constitutes a variation in procedure, but not a catastrophe.

Problem II-1 Total Loss of Thrust One Engine - 1st Stage

	Time Seconds	Cues Available
Malfunction begins	T + 2.0	Rapid loss axial accel. feel; Rapid decrease axial accel. instr. reading from 1.31 g to 0.64 g.
	T + 2.3	Noise level reduced by one/half - engine I light comes on.
	T + 3.7	Abort light comes on.
Required completion of abort action	T + 4.26	
Seat must leave rail	T + 4.7	

Required Response Time 2.26 secs. after beginning of malfunction
0.56 secs. after abort light

This case was presented to each pilot one time. The pilots completed the abort action at T + 5.77 and T + 4.98 which was 1.51 seconds and 0.72 seconds late. There are several peculiarities about this case which are discussed in the following paragraphs.

Due to a discrepancy in the data used as the basis for this experiment, it was thought that the seat must clear the rail by T + 6.3 seconds instead of T + 4.7 seconds. Both pilots aborted successfully on this basis. According to the ground rules the pilots had to wait for the abort light to signify peak altitude before aborting. This method was used in the experiment to provide ground information to the subjects. In analyzing the results of the experiment the above discrepancy was discovered and it was found that only 0.56 second was available after the abort light came on for the pilot to complete the abort action. Had the discrepancy been known prior to the experiment the abort light would not have been used and the pilots would have aborted immediately after detecting loss of thrust.

The cues provide immediate identification of the malfunction and there is no doubt that a properly trained pilot could successfully abort in this case.

Problem II-2 Total Loss of Thrust One Engine - 1st Stage

	Time Seconds	Cues Available
Malfunction Begins	T + 15	Rapid loss of axial accel. feel; Rapid decrease axial accel. instr. reading from 1.40 g to 0.54 g.
	T + 15.3	Noise level reduced by one/half; Engine I light comes on.
	T + 35.2	Abort light comes on.
Required completion of abort action	T + 50	

This case is similar to the previous one except that the malfunction occurs later and consequently at a higher altitude. Both pilots successfully aborted.

Problem III-1 Total Loss of Thrust Both Engines - 1st Stage

	Time Seconds	Cues Available
Malfunction begins	T + 4.0	Abrupt loss axial accel. feel; abrupt decrease axial accel. instr. reading from 1.32 g to 0 g.
	T + 4.3	Total loss of noise; Engine I light comes on Vibration stops
	T + 5.2	Abort light comes on.
Required completion of abort action	T + 5.26	
Seat must clear rail	T + 5.7	

Required Response Time - 1.26 secs.

This case was presented to the two pilots a total of 4 times. In one run the pilot was 0.14 seconds late.

The axial acceleration feel, loss of noise, and engine I light provide immediate identification of the malfunction.

The cues are very sharp for this case and there is little doubt that a properly trained pilot could successfully abort in this case since the operational procedure will be to abort immediately on detecting a loss of thrust during the first 5 seconds after lift-off. In problem II-1 and III-1, the pilot could complete the abort action in less than 1.0 second after the malfunction begin.

Problem III-2 Total Loss of Thrust Both Engines - 1st Stage

	Time Seconds	Cues Available
Malfunction begins	T + 70.0	Abrupt loss axial accel. feel; abrupt decrease axial accel. instr. reading from 2.05 g to -1.20 g. Rapid increase in pitch angle and pitch rate.
	T + 70.1	Pitch transient - 0.22 g
	T + 70.3	Engine I light comes on; Complete loss of noise.
	T + 71.0	Att. rate light and guidance light come on.
Required completion of abort action	T + 71.46	
Catastrophe	T + 71.9	

Required Response Time - 1.46 secs.

Abrupt loss of longitudinal acceleration feel and noise, engine I light, and sharp pitch transient all provide immediate information that thrust has failed and a fast abort action is required. In all four runs the pilots responded well within the allowable time.

Problem V-4, V-10 Staging - No Fire Bolt Signal

	Time Seconds	Cues Available
Malfunction begins	T + 148.3	Rapid loss axial accel. feel.
	T + 149.0	Rapid decrease axial accel. instr. reading from 5.6 g to 0 g- stage light stays on - Engine I fuel and ox. gage needles do not drop to zero.
	T + 149.3	Engine II light goes out.
	T + 149.7 (see Appendix -Pg.2)	Abort light comes on (Problem V-10 only)
Required engine shutdown	T + 150.47	
Mild fire	T + 150.7	

Required Response Time 2.17 sec. after staging starts
1.47 sec. after stage light fails to go off
0.77 sec. after abort light comes on

The first positive cue is when the engine II light goes off and the stage light stays on. The Stage I pressure gages not dropping to zero is an immediate confirmation. Also in the actual circumstance the pilot would immediately note a nearly weightless state due to lack of thrust. In five of the six runs the pilots successfully aborted in time. In one run the pilot was 0.85 seconds late.

There is reason to believe that being late in shutting down the second stage engine would not actually be catastrophic. If the engine flame burns through the first stage oxidizer tank as predicted, probably the only consequence would be a fire which would still allow time to execute an escape in the spacecraft. It is also reasonable to assume that relatively little additional training would be required to eliminate the problem altogether. The cues are positive and immediate so the pilot should have no difficulty making an immediate decision to shut down the second stage engine.

Problem V-5, V-11 Staging - Excess Tail Off

	Time Seconds	Cues Available
Malfunction begins	T + 148.0	Loss axial accel. feel
	T + 148.3	Stage light comes on
	T + 149.0	Axial accel. instr. drops slowly from 1.5 g to 0 g. Stage light stays on - Engine 1 fuel and ox. gage indicators do not drop to zero
	T + 149.3	Engine II light goes out
	T + 149.7	Abort light comes on (Problem V-11 only)
Required engine shutdown	T + 150.47	
Mild fire	T + 150.7	

Required Response Time 2.17 seconds

These problems are the same as V-4 and V-10 except that there is a slightly slower decay of first stage thrust which was not discernible by the pilot. The pilots responded to the same cues and scored essentially the same with one of the six runs being 0.22 seconds late.

While a fire may result, if the engine is not shut down in time, as discussed previously, there would probably be no catastrophe.

The analyses have indicated there is a possibility of successfully completing the mission in spite of malfunctions such as Problems V-5, V-11, and the hazard involved in attempting to complete the mission may be acceptable.

Problem V-6 Staging - No Thrust Engine II

	Time Seconds	Cues Available
Malfunction begins	T + 148.3	Loss axial accel. feel - Noise level decreases to zero; Vibration stops
	T + 149.0	Axial accel. instr. drops to 0. Staging light remains on - Engine I fuel and ox. indicators do not drop to 0. Engine II fuel and ox. gage indicators stay at full indication
	T + 149.3	Engine II light stays on
Abort not time critical		

Absence of acceleration feel, noise and vibration, staging light and engine II light staying on, and pressure gage needles not dropping to zero are all positive indications that stage II engine did not start. Pilots had no difficulty interpreting the cues and executing an abort.

Problem V-7 Staging Low Thrust Engine II

	Time Seconds	Cues Available
Malfunction begins	T + 148.3	
	T + 149.0	Engine II light stays on Slower increase axial accel. instr.
Abort not time critical		

The engine II light staying on was the only discernible indication that the second stage engine was not thrusting properly. Noise, vibration, longitudinal acceleration feel, staging light going out, and pressure gages were all cues that the engine was burning and separation had occurred. Aborting was no problem. Even though the engine light is dualized and therefore reliable, in actual flight the pilot would in all probability, ask for ground confirmation before aborting.

Problem V-9 No Staging

	Time Seconds	Cues Available
Malfunction begins	T + 139.5	Stage light does not come on; Vibration stops; Engine I light comes on
	T + 149.0	Loss axial accel. feel Axial accel. instr. drops from 5.6 g to 0 g. Eng. I fuel and ox. gage indicators do not drop to zero. Engine II fuel and ox. gage indicators read full.
	T + 149.3	Engine II light does not go off
Abort not time critical		

The cues were easily diagnosed and the abort was made as required.

Problem VI-13-23, VI-45 Tank Press Loss - Stage I Fuel

Problem	Malfunction Begins	Catastrophe Time	Req'd. Compl. of Abort Action	Required R.T.
VI-13	T + 0	T + 1.5	T + 1.06	1.06
VI-14	T + 0	T + 5.1	T + 4.66	4.66
VI-15	T + 5.0	T + 7.2	T + 6.76	1.76
VI-16	T + 5.0	T + 10.2	T + 9.76	4.76
VI-17	T + 10.0	T + 18.5	T + 18.06	8.06
VI-19	T + 25.0	T + 32.5	T + 32.06	7.06
VI-20	T + 40.0	NAR	NAR	NAR
VI-21	T + 80.0	T + 125	T + 123.95	43.95
VI-22	T + 110.0	NAR	NAR	
VI-23	T + 130.0	NAR	NAR	
VI-45	T + 15.0	NAR	NAR	

The two pilots were presented these cases a total of 26 times. The pilots successfully aborted or decided not to abort in all cases except VI-13, 14, 15 and 16. These four cases were presented a total of 12 times, all of which resulted in late aborts.

Cases VI-13 and 15 are fast leaks that drop the tank pressure to the structural threshold in 1.5 and 2.2 seconds, respectively. Subtracting the seat cycle time of 0.44 second leaves the pilot with 1.06 and 1.76 seconds, respectively, to respond. This should be enough time for the pilot to respond if the gage is suitably marked. Certainly, cases VI-14 and 16 allow ample time for the pilot to respond since the required response times are 4.66 and 4.76 seconds, respectively.

The problem of late responses can be attributed to the fact that pilots were not advised of the correct seat and capsule cycle times prior to the simulation. Therefore, their attempts to avoid aborting until the last possible instant led to a series of late, but correct decisions. A pilot can learn to lead the critical pressure and pull the D-ring soon enough to complete his action before the pressure reaches the indicated limit, allowing for example, 0.44 seconds seat cycle time, he should lead the critical pressure by at least 2.5 psi for fast pressure drops. For slow pressure drops, he could let the tank pressure closely approach the structural limit before acting.

An automatic abort system with a malfunction detection system (MDS) sensor setting such as that shown on Figure 6-1 (δp = 5.0 psi above ambient down to 8.0 psia - see Figure 6.7.12 of Reference 2) would unnecessarily abort all cases similar to VI-45 where the tank pressure does not go below the minimum structural threshold, but does go below the MDS sensor setting. An autogenous pressure system malfunction resulting in this type of pressure decay occurred on 27 October 1962 at Cape Canaveral. Although the reduced data from the flight are not available, preliminary reports indicate that the degraded Titan II autogenous system operation would have caused an automatic system to abort the mission needlessly.

Programming a curve of the type shown as the MDS settings on Figure 6-1 requires a reliable static pressure source. A differential pressure sensor (tank pressure minus ambient) has been considered, but discarded because a suitable ambient pressure reference was not available.

Problem VI-24-33, VI-46 Tank Press Loss - Stage I Oxidizer

Problem	Malfunction Begins	Catastrophe Time	Req'd. Completion of Abort Action	Req'd. R. T.
VI-24	T + 0	T + 4.3	T + 3.86	3.86
VI-26	T + 5.0	T + 8.7	T + 8.26	3.26
VI-27	T + 5.0	T + 14.3	T + 13.86	8.86
VI-28	T + 10.0	T + 14.6	T + 14.16	4.16
VI-29	T + 15.0	T + 28.7	T + 28.26	13.26
VI-30	T + 25.0	NAR	NAR	
VI-31	T + 40.0	NAR	NAR	
VI-32	T + 80.0	NAR	NAR	
VI-33	T + 130.0	NAR	NAR	
VI-46	T + 5.0	NAR	NAR	

The two pilots were presented these cases a total of 24 times. The pilots successfully aborted or decided not to abort in all cases except VI-26, 27, 28 and 46. Cases VI-26, 27 and 28 were presented to the pilots 10 times, 8 of which were in excess of the allowed time. The discussion for cases VI-13 through 16 is applicable here also.

Case VI-46 did not require an abort, but in one run a pilot did abort. The pressure reading at the time he aborted was 2 psi above the structural limit. It is believed that more training would have prevented this error. It was the only time that either pilot aborted unnecessarily in cases of pressure failures.

Problem VI-34-41 Tank Press Loss -
Stage II Fuel

Problem	Malfunction Begins	Catastrophe Time	Req'd. Compl. of Abort Action	Req'd. R. T.
VI-34	T + 0	T + 148.3	T + 120.0	
VI-35	T + 10.0	T + 148.3	T + 120.0	
VI-36	T + 40.0	T + 148.3	T + 120.0	
VI-37	T + 148.3	T + 157.3	T + 156.25	7.95
VI-38	T + 153.3	T + 154.8	T + 153.75	.45
VI-39	T + 168.3	T + 171.4	T + 170.35	2.05
VI-40	T + 168.3	T + 212.6	T + 211.55	43.25
VI-41	T + 268.3	T + 324.8	T + 323.75	55.45

Cases VI-34, 35 and 36 were stage II fuel pressure drops during stage I operation. Since the fastest leaks considered to be realistic possibilities cannot drop the pressure fast enough to exceed structural limits it was only necessary for the pilot to observe that the pressure was below the allowable 40 psia for starting the stage II engine and execute an abort after reaching spacecraft escape altitude and before staging. Both pilots aborted correctly in the six times that these cases were presented. Subsequent to the experiment information was received per reference 6 that the minimum allowable pressure for starting the stage II engine is 30 psia instead of 40 psia which was on the gage during the experiment. This change has no effect on the results of the experiment.

Cases VI-37, 38, 39, 40 and 41 were stage II fuel pressure drops during stage II operation. These cases were presented to the pilots a total of 14 times. The pilots successfully aborted in all cases except VI-38 and VI-39. Each of these two cases was presented four times. The pilots were late all four times in case VI-38 and one time in case VI-39.

The spacecraft required 1.05 seconds after initiation to separate from the booster. In case VI-38 the pressure drops to the structural limit in 1.5 seconds which leaves the pilot 0.45 second to respond. Since this is approximately the basal response time of the pilot and some time is required to detect an abnormal pressure drop, it is impossible for the pilot to act quickly enough. It is very unlikely that an automatic system could be made to succeed in this case and certainly not without greatly increasing the probability of unnecessary aborts since the sensor setting would have to be only slightly less than normal minimum pressure which means that every leak of any kind that drops the pressure below normal minimum would be aborted.

Admitting that a highly improbable large leak can occur which would not allow the pilot and escape system to separate from the spacecraft before the tank pressure reaches the limit, what will be the consequence? When tank pressure reaches the structural limit, stage II engine thrust will collapse the lower end of the fuel tank and the oxidizer feed line inside the fuel tank. Fuel and oxidizer will mix and a hypergolic fire will occur. The spacecraft can readily withstand the fireball since the blast effects would be very small and the heating of the spacecraft skin would be well below limits. Martin development tests of the Titan II destruct system indicate that the highest radiant heat pulse attainable (by deliberately mixing hypergolic fuel and oxidizer) is 5% of theoretical. To get 5% requires complete separation of adjacent tank domes by means of pyrotechnic charges. Thus the possibility of successful abort is good even for slightly late pilot reaction.

Problem VI-42-44 Tank Press Loss - Stage II Ox.

Problem	Malfunction Begins	Catastrophe Time	Req'd. Compl. of Abort Action	Req'd. R. T.
VI-42	T + 0	T + 148.3	T + 120.0 +	
VI-43	T + 158.3	NAR		
VI-44	T + 158.3	NAR		

These cases were presented to the two pilots a total of six times and there were no errors scored. Subsequent to the experiment, it was learned that there is no reason to abort prior to staging, as was done in case VI-42, when the oxidizer tank pressure is below the S on the gage. The worst consequence of allowing staging to take place would be that the engine may not start. The fastest leaks considered to be realistic possibilities cannot drop the stage II oxidizer pressure below structural limits during stage I operation and vapor pressure will maintain the tank above the engine running constraint pressure during stage II operation. Therefore, there will never be any catastrophic circumstance to result from stage II oxidizer tank pressure.

The current design of the pressure gage should be modified so that the cross-hatched zone applies only to the fuel gage. (See Page 57). The only use the pilot will have for the stage II oxidizer gage is to advise him that the stage II engine may not start at staging if the pressure is below normal.

Problem VII-1 Adverse Roll

	Time Seconds	Cues Available
Malfunction begins	T + 5.0	Attitude ball rotates in wrong direction
Switch to secondary guidance		

This case was included in the experiment to determine whether or not the pilot could, without ground assistance, detect a failure of the guidance system and switch to secondary guidance. The case was presented to each pilot one time. One pilot detected the malfunction and switched to secondary guidance 4.79 seconds after the malfunction began. The other pilot detected the malfunction but did not switch to secondary guidance since he was not aware of the instruction to do so.*

The pilot can be expected to take corrective action in the event of guidance errors large enough and fast enough to detect on the attitude and rate displays. Smaller errors would be detected by ground control in sufficient time to advise the pilot to switch to secondary guidance. Very fast guidance errors would cause the automatic rate sensors to switch to secondary guidance.

*In the briefing, the pilots were instructed to switch to secondary guidance if they detected any unusual behavior of the attitude display which would signify faulty guidance.

Problem VIII-3 DC Power Failure

	Time Seconds	Cues Available
Malfunction begins	T + 12.0	Change of heading angle Half of engine I and II fuel and ox. indicators go to zero Moving base creates yawing accel.
	T + 12.5	Attitude rate light and guidance light come on. Pressure indicators return to normal. *
	T + 12.7	Attitude rate light goes out
	T + 20.4	Pitch, yaw and roll normal
No action required		

One half of each fuel and oxidizer pressure indicator dropping to zero was an immediate evidence of loss of DC power. The subsequent yaw rate exceeded the limits so rapidly that automatic switchover to secondary guidance occurred before the pilots had a chance to respond, as was expected. The secondary guidance system corrected the problem and the pilots simply interpreted what had happened.

* The pressure indicators will not return to normal in the Gemini vehicle as was assumed during the experiment.

Problem VIII-4 DC Power Failure

	Time Seconds	Cues Available
Malfunction begins	T + 95.0	Slow change in pitch angle and rate Moving base creates slight pitching accel. Half of the fuel and ox. indicators go to 0
Switch to secondary guidance		

One half of each fuel and oxidizer indicator dropping to zero was an immediate evidence of loss of DC power. The slow deviation of pitch angle and rate from normal was barely discernible. Each pilot was presented this case two times. One pilot responded correctly and switched to secondary guidance in 3.78 and 3.99 seconds after the malfunction began. The other pilot, during one run, knew that DC power was abnormal, but thought guidance was normal and did not switch to secondary guidance. In this case, ground control could have advised the pilot of a gradual deviation from course in time for him to switch to secondary guidance. In the other run, this pilot inadvertently aborted which would have been an unnecessary loss of the mission. The tank pressure gages have been modified to fail up in case of power loss to preclude inadvertent aborts even though such actions could be eliminated by training.

Problem IX - 5 Instr. Malfunction Stage I Ox.

	Time Seconds	Cues Available
Malfunction begins	T + 10	B indicator of stage I ox. pressure drops to 0 slowly
No abort required		

This case was presented to each pilot one time. Both pilots properly identified the malfunction as an instrument failure and did not abort.

Problem IX - 6 Instr. Malfunction Stage I Ox.

	Time Seconds	Cues Available
Malfunction begins	T + 0	B indicator stage I Ox. drops to zero fast
No abort required		

This case was presented to each pilot one time. Both pilots properly identified the malfunction as an instrument failure and did not abort.

Problem IX-7 Instr. Malfunction Stage I Fuel

	Time Seconds	Cues Available
Malfunction begins	T + 10	B indicator stage I fuel drops to zero fast
No abort required		

This case was presented to each pilot one time. One pilot properly identified the malfunction as an instrument failure and did not abort. The other pilot aborted and thus scored an unnecessary loss of a mission.

Since it is necessary for the pilot to be ready for a fast drop in tank pressure, the sudden drop of one half of the pressure indicator can cause the pilot to respond in error. Subsequent to this experiment the Gemini design was changed so that the pressure indicator pointers will move upward if they fail rather than downward. This should prevent pilot error since an upward movement of the failed indicator would be instantly distinguishable from a pressure drop.

Problem X-2 Early Staging

	Time Seconds	Cues Available
Staging initiated	T + 140.3	Staging sequence begins eight seconds early.
No abort required		

Although staging normally occurs at T + 148.3 seconds, it can occur anytime after T + 139.5 seconds without jeopardizing the mission. It was felt that staging earlier than T + 148.3 seconds might cause the pilot to think a malfunction had occurred and thus execute an unnecessary abort. This case was presented to each pilot one time and both pilots correctly identified the event and did not abort.

Problem X-3 Engine I Light Not Disabled

	Time Seconds	Cues Available
Staging Initiated	T + 139.5	
	T + 148.3	Engine I light comes on
	T + 149.0	Engine I light goes off
No abort required		

Normally the engine I light was disabled when the staging cycle was armed to prevent the light from flashing as engine I chamber pressure dropped below 65% during normal staging. There was reason to believe that the 0.7 second flash of this red light might cause the pilot to abort. This case was presented to each pilot one time and neither of them aborted.

Since this was the unusual rather than the usual indicator sequence at staging and it still did not cause the pilots to abort, it is concluded that based on these limited trials, the disarming feature for this light is unnecessary.

Problem XI-1 Engine I Light Malfunction

	Time Seconds	Cues Available
Light not disabled	T + 2.3	Engine one light comes on
No abort required		

Since the instrument lights were dualized this malfunction was included in the experiment to obtain some measure of whether the pilots were responding to lights or whether they were aborting only if confirming cues were present. The case was presented to each pilot two times and neither pilot aborted. This result plus comments regarding other similar cases indicated the subjects were not aborting on a single non-confirmed cue.

5.2 MODE SELECTION

The pilot's action involved selection between three modes, namely (1) seat ejection, (2) stage II engine shutdown and spacecraft abort, and (3) secondary guidance operation. Since the seat ejection mode was used from lift-off to T + 95 seconds and stage II engine shutdown and spacecraft abort mode was used thereafter, the pilots kept their hands on the seat "D" ring until T + 95 seconds after which they removed their hands from the "D" ring and placed the left hand on the engine shutdown and spacecraft abort switch. This procedure eliminates any need for choosing between the two modes at the time of a malfunction and leaves the pilot with the simple task of changing hand position at the proper time.

5.3 BOOSTER SHUTDOWN - CAPSULE ABORT SWITCH

For the Gemini Abort simulation program a three position toggle switch was used for booster shutdown and capsule abort. The center position being neutral, down was booster shutdown and up was capsule abort. It became quite obvious early in the experiment that this type of switch was totally unsatisfactory for such critical operations. The switch was exceedingly sensitive, unprotected from inadvertent, operation, awkward to reach, and not conducive to "off - one position delay - second position" type operation.

Subsequently, the design of the booster shutdown and capsule abort mechanism has been changed to a "gear shift" type handle with lock-detent features. Vought concurs with this design modification.

6.0 CONCLUSIONS

1. Onboard pilot initiated abort is feasible and desirable. Even though some late responses were evident in this program, they can be reduced to negligible probabilities by more training.

2. Using manual abort, over-all crew safety during the launch phase is considered equivalent to that achievable in experimental flights of high performance aircraft.

3. A number of the possible malfunctions, particularly tank pressure losses, approach the threshold of catastrophe at various rates. In many of these cases the pilot is able to judge from the rate of system degradation that an abort is not required even though system performance is not normal.

4. The most exacting requirements that either a manual or automatic system must satisfy occur during the five seconds following lift-off and at staging. During approximately the first five seconds after lift-off, there is a period in which total engine failure and fast tank pressure losses are critical. However, the probability of a severe malfunction during this brief period is considered to be extremely low. The situation is similar just after staging.

5. All other simulated malfunction circumstances that could lead to catastrophe, including staging malfunctions are safely within the manual abort capability.

6. The Gemini launch vehicle display group is adequate for the boost phase of the mission, although improvements could be achieved by modifying the analog tank pressure indicator and by adding an audible tick in the event timer.

7. The audio and kinesthetic cues are extremely valuable in evaluating an emergency condition during boost. In some cases such cues should be considered primary and not as backups to the displays. Therefore, a high fidelity simulation on a moving base device, such as the Manned Aerospace Flight Simulator, is necessary for launch phase study and training.

6.1 RECOMMENDATIONS

6.1.1 Cockpit Displays

It is recommended that two modifications be made to the cockpit displays as follows:

1. Pressure Gages - The stage I fuel and oxidizer gage should have a yellow band between 15 and 17.5 psia which corresponds to the 2.5 psia pressure drop that will occur in 0.44 second (seat system lag) as a result of large leaks. The NPSH limit on the stage II gage is applicable to fuel pressure only, so the crosshatched area should only be on the left hand side. Figure 7 shows a recommended design. These modifications do not require any mechanical changes in the current instrument design. (It is assumed that the current design includes the modification that causes the needles to move upward in the event of DC power or open instrument circuit failures).

2. Event Timer - The event timer should include an audible ticking at each second. This can be accomplished in several ways, but the preferred method is for the timer to cause an electrical pulse which is relayed directly to the pilots earphones. This feature is very beneficial to the pilot during the boost period, but would be of no value and probably annoying thereafter. A separate manual volume control would allow the pilot to cut out the pulse as well as regulate it as required.

6.1.2 Operational Procedures

It is recommended that the operational procedures include the following:

1. In the event of any loss of thrust prior to T + 5 seconds abort immediately.

2. If a stage I fuel or oxidizer pressure failure occurs, abort before the indicator reaches the yellow band if it is a fast drop. For slower drops, abort before the indicator reaches the pressure limit allowing 1/2 second for seat lag.

6.1.3 Training

It is recommended that the Gemini pilots be extensively trained in the abort monitoring task. Thorough refresher training should proceed the Gemini flight. Motion and noise cues are essential to adequate training.

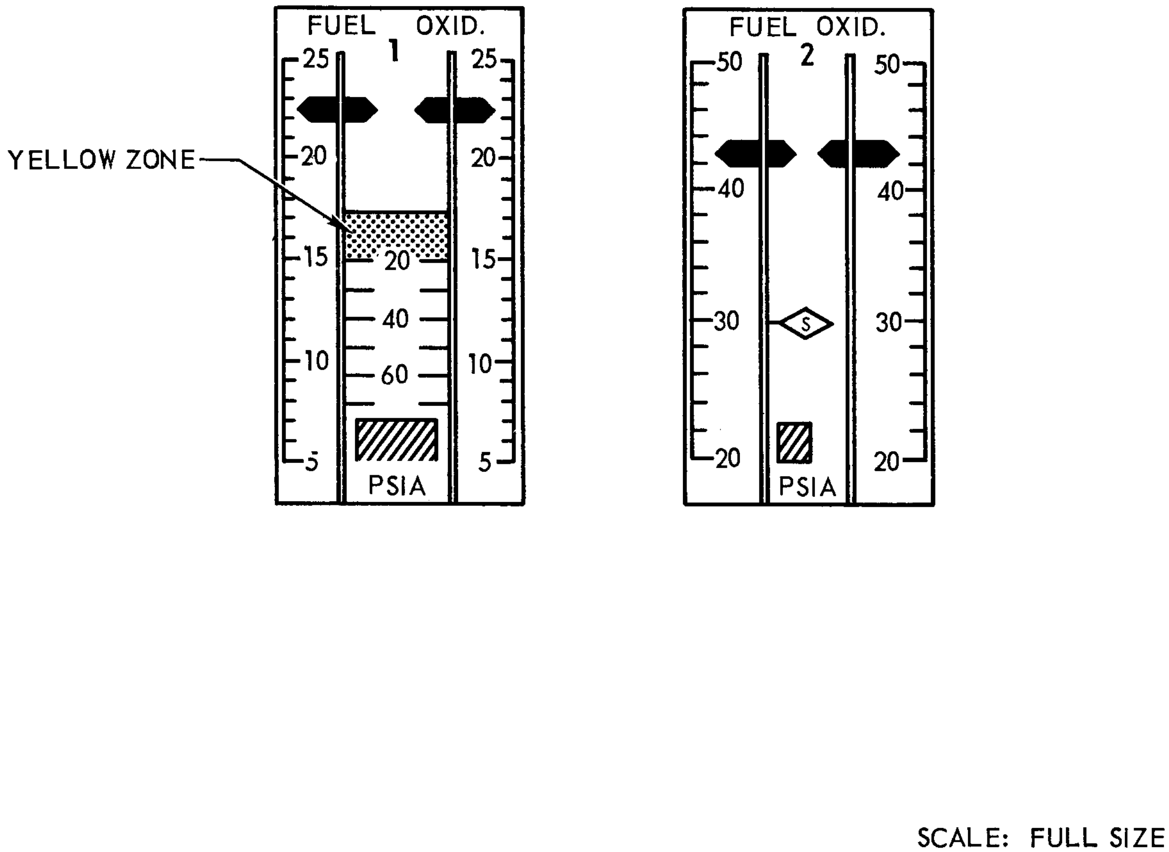

FIGURE 7 – PROPOSED TANK PRESSURE DISPLAYS

REFERENCES

1. Vought Astronautics — Simulator Study of Gemini Boost Abort Situations, NASA Contract No. NAS9-255, Report No. 00.51, July 1962. Report CONFIDENTIAL

2. Cook, C. — Malfunction Detection System Design Study, Dyna-Soar Step 1, DS-26-61, Rev. A, The Martin Co. Contract AF(04)-(647)-610, Report CONFIDENTIAL

3. Space Systems Division — Malfunction Detection System Trade Study, T.N. LV-6, Gemini Program Launch Vehicle System, The Martin Marietta Corporation, Report CONFIDENTIAL

4. Space Systems Division — Evaluation of Guidance and Controls Redundancy and Backup Schemes, T.N. LV-7, Gemini Program, Launch Vehicle System, The Martin Marietta Corporation, Report CONFIDENTIAL

5. Richard R. Carley — Pressure Failure Analysis Data for Chance Vought Simulation Memorandum for Launch Vehicle Manager, 2 July 1962, Memorandum not classified.

6. J. U. LaFrance — Recommendation of Minimum Stage II Fuel Tank Pressure at Staging for Safety Engine Start and Stage II Flight, The Martin Marietta Corporation Ltr. J-3134/Jul, 8 Oct. 1962. Letter not classified.

7. J. U. LaFrance — Integrated Abort Program Status Report No. 1, T.N. LV-97, Gemini Program, Launch Vehicle Program, The Martin Marietta Corporation, Report SECRET.

APPENDIX A

1. Malfunction Data

Table A-1 is the master list of simulated runs which was used for the follow-on study. Several of the cases are identical with those in the initial program; however, numerous deviations and additions are to be found. It was the opinion of NASA that many tank pressure malfunctions should be mechanized. Hardover engine failures were deleted from the present study. The following types of situations were instrumented in the simulation equipment:

I	Partial loss of thrust of one engine	1 case
II	Total loss of thrust of one engine	2 cases
III	Total loss of thrust of both engines	2 cases
V	Staging failures	7 cases
VI	Tank pressure loss	32 cases
VII	Adverse roll	1 case
VIII	DC power failure	2 cases
IX	Instrument malfunction	3 cases
X	Deviation runs	2 cases
XI	Light malfunction	1 case
	TOTAL	53 cases

In Table A-1, the abort time represents the latest time at which the seat or spacecraft can be totally separated from the remainder of the craft in order that the abort be successful. The ground rule on separation time is as follows:

Seat Eject (before T + 95.0) - 0.44 sec.

Spacecraft separate (after T + 95.0) - 1.05 sec.

Required reaction time is then the difference between the time the malfunction begins and the catastrophe time less the separation time, or $RT = T_c - T_m - T_s$ where

RF - Required reaction time
T_c - Time catastrophe occurs
T_m - Time malfunction begins
T_s - Response time of system

For the cases wherein it is necessary only to shut down the Stage II booster engine, the maximum pilot response time is 2.17 seconds after staging begins as outlined in reference (7), Figure 10.1-3. Some of the situations do not require a short response time. These are denoted N.D.R.T. or "No Definite Response Time" since they are not time critical. Runs VII-1 and VIII-4 require a guidance switchover; the rule is to initiate the action as soon as possible.

2. Examples of Typical Abort Situations

Some typical examples of abort situations, showing the manner in which they were analyzed, are presented as follows (see Table A-1 and supporting figures):

Example (1): Problem II-2, total loss of thrust of one first stage engine at T + 15.0.

At T + 15.0 a malfunction causes one engine to shutdown in the minimum time causing the chamber pressure to drop to 65% in 0.3 sec; this causes the Engine 1 chamber pressure light to come on at T + 15.3. A secondary indication of thrust loss is a decrease in axial load; this decrease is shown by the g meter and the test subject also experiences it as the gross pitch position of the moving base is decreased. Since a total loss of one engine at this time will result in the booster falling to the ground, it is necessary for the crew to eject sometime before approximately T + 60.0. Maximum altitude is achieved at T + 35.2; this is the time when the abort light comes on. In order to determine a conservative required reaction time, the abort time was selected as T + 50.0 + which yielded a pilot reaction time of 34.56 seconds under the assumption that the seat eject separation time was 0.44 sec.

Example (2): Problem V-4, No Fire Bolts Signal

The Fire Bolts Signal is not present at T + 148.3; consequently, the stages cannot separate. Starting of the second stage engine at the usual time presents the problem (fire in the hole). Indications to the test subject are: (a) stage light stays on after T + 148.3, (b) g meter and gross pitch drop off and (c) first stage tank pressure indicators remain where they were subsequent to first stage shutdown. The correct pilot action is to shutdown the second stage engine sometime before T + 150.47 in order to prevent an explosion. The required pilot reaction time is 2.17 sec. after staging begins.

Example (3): Problem VI-15, Tank Pressure Loss

A malfunction occurs at T + 5.0 which causes the pressure in the first stage fuel tank to drop rapidly below the minimum structural threshold. The only indication which the test subject has is the tank pressure instrument. Catastrophe occurs at T + 7.2; therefore, the maximum allowable pilot reaction time is 1.76 sec. allowing 0.44 sec. for separation.

Example (4): Problem VI-45, Tank Pressure Loss

This problem presents a situation wherein the pressure in the first stage fuel tank drops off fairly rapidly but never reaches the minimum structural threshold and consequently does not require an abort. The minimum allowable tank pressure for the first 60 seconds is indicated on the face of the instrument; after this time the pressure must not drop to the cross-hatched area.

Example (5): Problem VIII-3, DC Power Failure

A failure of the IPS occurs at T + 12.0 and an automatic guidance switchover follows at T + 12.5. An abort is not required. The attitude rate and guidance lights come on at T + 12.5 and the attitude rate light goes off at T + 12.7. Appropriate transients are indicated by the attitude display, DC voltmeter and the "A" indicators of all four tank pressure instruments since they are driven by the IPS.

Example (6): Problem IX-5, Instrument Malfunction

A slow drop of the "B" indicator on the stage one oxidizer tank pressure instrument begins at T + 10.0. The fact that only one indicator falls tells the test subject that he has an instrument malfunction; an abort is not required.

Example (7): Problem X-2, Deviation Run

This run is different from the standard boost only in the time of staging initiation which occurs at T + 140.3. This time differential is considered too short to seriously degrade the injection. Appropriate translations occur in the timing of the engine 2 and stage lights, g meter and tank pressure instruments. Also, the noise and gondola motions are synchronized to accommodate the early stage initiation.

[redacted]

TABLE A-1 MASTER LIST OF SIMULATED RUNS

PROB. NO.	TYPE OF RUN	MALF. BEGINS	ABORT BY	REQ. REACTION TIME	INDICATOR LIGHTS: ABORT		ATT. RATE		GUIDANCE		ENG. 1		ENG. 2		STAGE		PANEL INDICATOR TIME HISTORY: θ		φ	ψ		D.C.	AXIAL	LAT.	NORMAL	STAGE 1 FUEL		STAGE 1 OXID.		STAGE 2 FUEL		STAGE 2 OXID.	
					ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	RATE	DISPL.	DISPL.	RATE	DISPL.	VOLTS	LOAD	ACCEL.	ACCEL.	A	B	A	B	A	B	A	B
I. PARTIAL LOSS OF THRUST – ONE ENGINE (1ST STAGE)																																	
I–4		T + 5.0	T + 120⁺		T + 120						T – 10.0 T + 6.0	T – 3.0											FIG. 1–1										
II. TOTAL LOSS OF THRUST – ONE ENGINE (1ST STAGE)																																	
II–1		T + 2.0	T + 4.7	2.26	T + 3.7						T – 10.0 T + 2.3	T – 3.0											FIG. 2–1										
II–2		T + 15.0	T + 50⁺	34.56	T + 35.2						T – 10.0 T + 15.3	T – 3.0											FIG. 2–1										
III. TOTAL LOSS OF THRUST – BOTH ENGINES (1ST STAGE)																																	
III–1		T + 4.0	T + 5.7	1.26	T + 5.2						T – 10.0 T + 4.3	T – 3.0											FIG. 2–1										
III–2		T + 70.0	T + 71.9	1.46			T + 71.0	T – 10.	T + 71.0	T – 10.0	T – 10.0 T + 70.3	T – 3.0					FIG. 3–1	FIG. 3–2					FIG. 2–1		FIG. 3–3								
V. STAGING																																	
V–4	NO FIRE BOLTS SIGNAL	T + 148.3	T + 150.7	2.17											T + 148.3 STAYS ON	T – 10.0							FIG. 2–1			FIG. 6–2	FIG. 6–2	FIG. 6–4	FIG. 6–4				
V–5	EXCESS STAGE I TAILOFF	T + 148.0	T + 150.7	2.17											T + 148.3 STAYS ON	T – 10.0							FIG. 2–1			FIG. 6–2	FIG. 6–2	FIG. 6–4	FIG. 6–4				
V–6	STAGE II FAILS TO BOOTSTRAP – NO THRUST	T + 148.3	T + 160⁺										T – 10.0	STAYS ON	T + 148.3 STAYS ON	T – 10.0							FIG. 2–1			FIG. 6–2	FIG. 6–2	FIG. 6–4	FIG. 6–4	FIG. 6–6	FIG. 6–6	FIG. 6–8	FIG. 6–8
V–7	STAGE II FAILS TO BOOTSTRAP – LOW THRUST	T + 148.3	N.D.R.T.⁺⁺										T – 10.0	STAYS ON									FIG. 2–1										
V–9	NO STAGING	T + 139.5	T + 160⁺								T – 10.0 T + 148.3	T – 3.0	T – 10.0	STAYS ON	STAYS OFF	T – 10.0							FIG. 2–1			FIG. 6–2	FIG. 6–2	FIG. 6–4	FIG. 6–4	FIG. 6–6	FIG. 6–6	FIG. 6–8	FIG. 6–8
V–10	NO FIRE BOLTS SIGNAL	T + 148.3	T + 150.7	2.17	T + 149.7										T + 148.3 STAYS ON	T – 10.0							FIG. 2–1			FIG. 6–2	FIG. 6–2	FIG. 6–4	FIG. 6–4				
V–11	EXCESS STAGE I TAILOFF	T + 148.0	T + 150.7	2.17	T + 149.7										T + 148.3 STAYS ON	T – 10.0							FIG. 2–1			FIG. 6–2	FIG. 6–2	FIG. 6–4	FIG. 6–4				
VI. TANK PRESSURE LOSS																																	
VI–13	STAGE I FUEL	T + 0	T + 1.5	1.06																						FIG. 6–1	FIG. 6–1						
VI–14	STAGE I FUEL	T + 0	T + 5.1	4.66																						FIG. 6–1	FIG. 6–1						
VI–15	STAGE I FUEL	T + 5.0	T + 7.2	1.76																						FIG. 6–1	FIG. 6–1						
VI–16	STAGE I FUEL	T + 5.0	T + 10.2	4.76																						FIG. 6–1	FIG. 6–1						
VI–17	STAGE I FUEL	T + 10.0	T + 18.5	8.06																						FIG. 6–1	FIG. 6–1						
VI–19	STAGE I FUEL	T + 25.0	T + 32.5	7.06																						FIG. 6–1	FIG. 6–1						
VI–20	STAGE I FUEL	T + 40.0	NAR*																							FIG. 6–1	FIG. 6–1						
VI–21	STAGE I FUEL	T + 80.0	T + 125.0	43.95																						FIG. 6–1	FIG. 6–1						
VI–22	STAGE I FUEL	T + 110.0	NAR																							FIG. 6–1	FIG. 6–1						
VI–23	STAGE I FUEL	T + 130.0	NAR																							FIG. 6–1	FIG. 6–1						
VI–45	STAGE I FUEL	T + 15.0	NAR																							FIG. 6–1	FIG. 6–1						
VI–24	STAGE I OXIDIZER	T + 0	T + 4.3	3.86																								FIG. 6–3	FIG. 6–3				
VI–26	STAGE I OXIDIZER	T + 5.0	T + 8.7	3.26																								FIG. 6–3	FIG. 6–3				
VI–27	STAGE I OXIDIZER	T + 5.0	T + 14.3	8.86																								FIG. 6–3	FIG. 6–3				
VI–28	STAGE I OXIDIZER	T + 10.0	T + 14.6	4.16																								FIG. 6–3	FIG. 6–3				
VI–29	STAGE I OXIDIZER	T + 15.0	T + 28.7	13.26																								FIG. 6–3	FIG. 6–3				
VI–30	STAGE I OXIDIZER	T + 25.0	NAR																									FIG. 6–3	FIG. 6–3				
VI–31	STAGE I OXIDIZER	T + 40.0	NAR																									FIG. 6–3	FIG. 6–3				
VI–32	STAGE I OXIDIZER	T + 80.0	NAR																									FIG. 6–3	FIG. 6–3				
VI–33	STAGE I OXIDIZER	T + 130.0	NAR																									FIG. 6–3	FIG. 6–3				
VI–46	STAGE I OXIDIZER	T + 5.0	NAR																									FIG. 6–3	FIG. 6–3				
VI–34	STAGE II FUEL DURING STAGE I OPERATION	T + 0	T + 148.3																											FIG. 6–5	FIG. 6–5		
VI–35	STAGE II FUEL DURING STAGE I OPERATION	T + 10.0	T + 148.3																											FIG. 6–5	FIG. 6–5		
VI–36	STAGE II FUEL DURING STAGE I OPERATION	T + 40.0	T + 148.3																											FIG. 6–5	FIG. 6–5		
VI–37	STAGE II FUEL DURING STAGE II OPERATION	T + 148.3	T + 157.3	7.95																										FIG. 6–6	FIG. 6–6		
VI–38	STAGE II FUEL DURING STAGE II OPERATION	T + 153.3	T + 154.8	0.45																										FIG. 6–6	FIG. 6–6		
VI–39	STAGE II FUEL DURING STAGE II OPERATION	T + 168.3	T + 171.4	2.05																										FIG. 6–6	FIG. 6–6		
VI–40	STAGE II FUEL DURING STAGE II OPERATION	T + 168.3	T + 212.6	43.25																										FIG. 6–6	FIG. 6–6		
VI–41	STAGE II FUEL DURING STAGE II OPERATION	T + 268.3	T + 324.8	55.45																										FIG. 6–6	FIG. 6–6		
VI–42	STAGE II OXIDIZER DURING STAGE I OPERATION	T + 0	T + 148.3																													FIG. 6–7	FIG. 6–7
VI–43	STAGE II OXIDIZER DURING STAGE II OPERATION	T + 158.3	NAR																													FIG. 6–8	FIG. 6–8
VI–44	STAGE II OXIDIZER DURING STAGE II OPERATION	T + 158.3	NAR																													FIG. 6–8	FIG. 6–8
VII. ADVERSE ROLL																																	
VII–1		T + 5.0																			FIG. 7–1												
VIII. D.C. POWER FAILURES																																	
VIII–3		T + 12.0	NAR				T + 12.5	T – 10.0 T + 12.7	T + 12.5	T – 10.0								FIG. 3–2	FIG. 8–1	FIG. 8–2	FIG. 7–1	FIG. 8–3		FIG. 8–4		FIG. 6–2		FIG. 6–4		FIG. 6–5		FIG. 6–7	
VIII–4		T + 95.0															FIG. 3–1	FIG. 3–2				FIG. 8–3			FIG. 3–3	FIG. 6–2		FIG. 6–4		FIG. 6–5		FIG. 6–7	
IX. INSTRUMENT MALFUNCTIONS																																	
IX–5	STAGE I OXIDIZER PRESSURE	T + 10.0	NAR																										FIG. 6–4				
IX–6	STAGE I OXIDIZER PRESSURE	T + 0	NAR																										FIG. 6–4				
IX–7	STAGE I FUEL PRESSURE	T + 10.0	NAR																								FIG. 6–1						
X. NORMAL BOOST																																	
X–1	STANDARD					T – 10.0		T – 10.0		T – 10.0	T – 10.0	T – 3.0	T – 10.0	T + 149.3	T + 148.3	T – 10.0 T + 149.0	FIG. 10–2	FIG. 10–1			FIG. 10–2		FIG. 10–1		FIG. 10–1	FIG. 6–1	FIG. 6–1	FIG. 6–3	FIG. 6–3	FIG. 6–5	FIG. 6–5	FIG. 6–7	FIG. 6–7
X–2	EARLY STAGING												T – 10.0	T + 141.3	T + 140.3	T – 10.0 T + 141.0							FIG. 1–1			FIG. 6–2	FIG. 6–2	FIG. 6–4	FIG. 6–4	FIG. 6–6	FIG. 6–6	FIG. 6–8	FIG. 6–8
X–3	ENGINE I LIGHT NOT DISABLED AT T+ 139.5										T – 10.0 T + 148.3	T – 3.0 T + 149.0																					
XI. WARNING LIGHT FAILURE																																	
XI–1	ENGINE I LIGHT	T + 2.3	NAR								T – 10.0 T + 2.3	T – 3.0																					

*NO ACTION REQUIRED
⁺⁺ NO DEFINITE RESPONSE TIME

~~CONFIDENTIAL~~

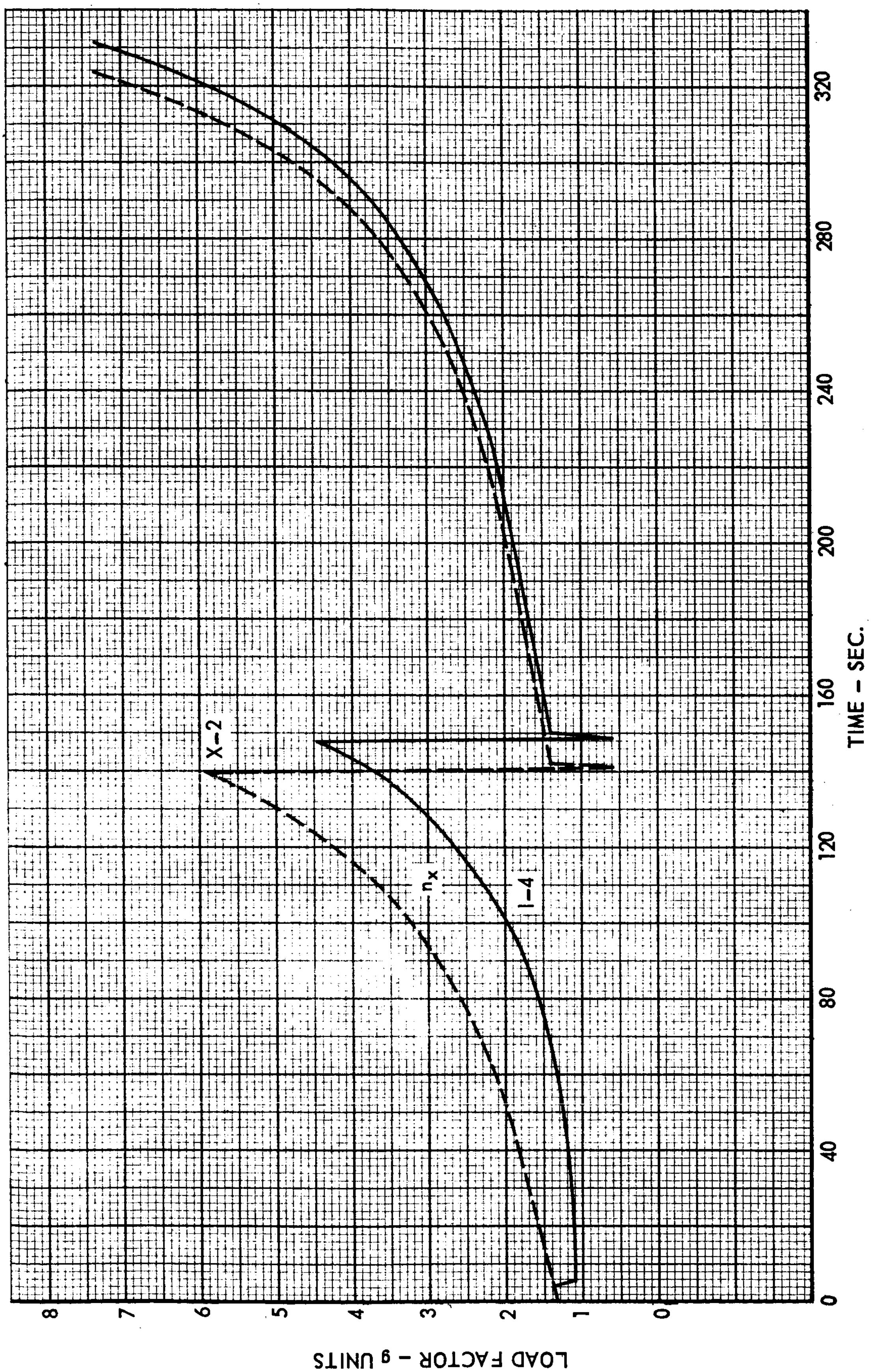

FIGURE 1-1 AXIAL LOAD

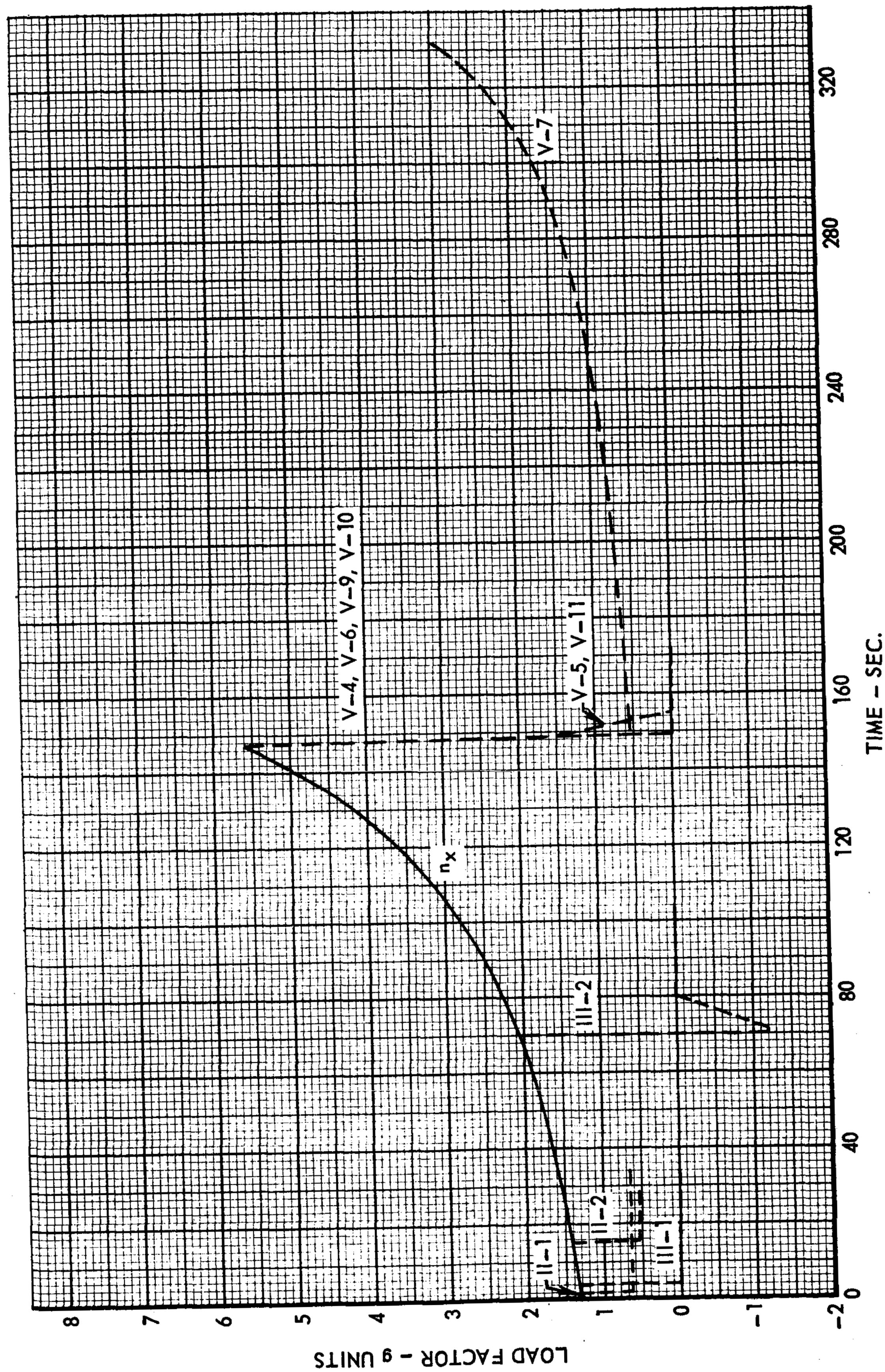

FIGURE 2-1 AXIAL LOAD

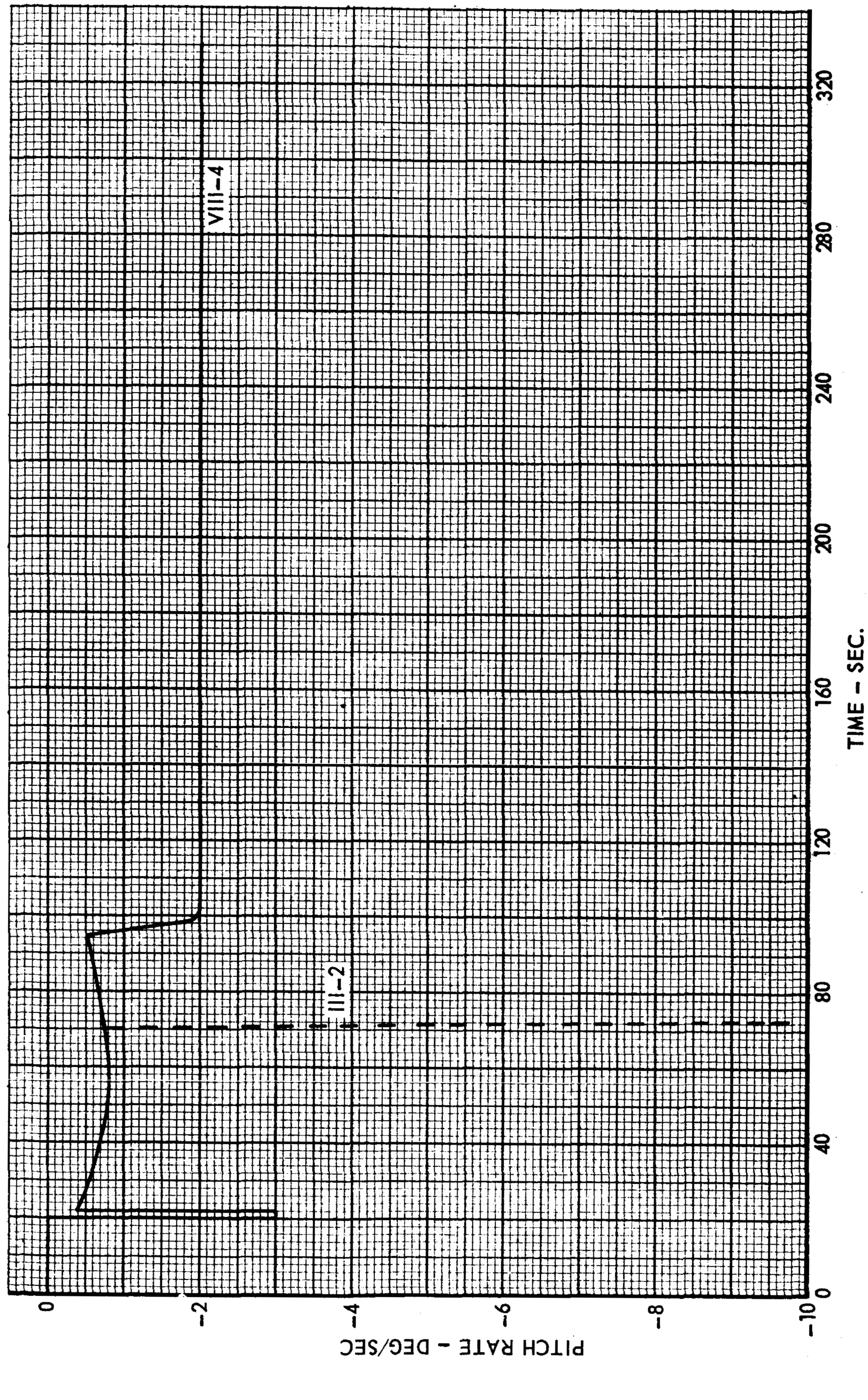

FIGURE 3-1 PITCH RATE

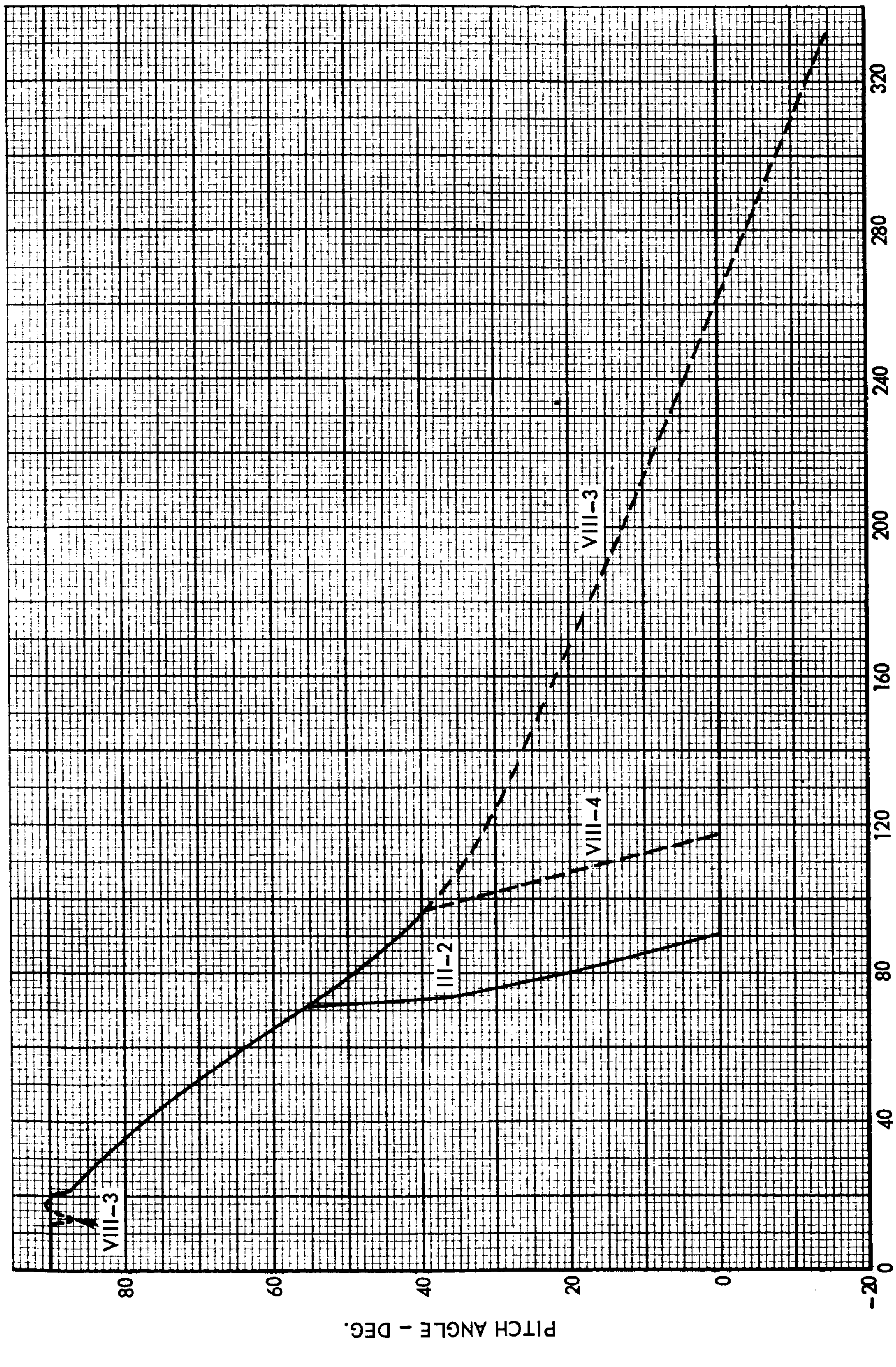

FIGURE 3-2 PITCH ANGLE

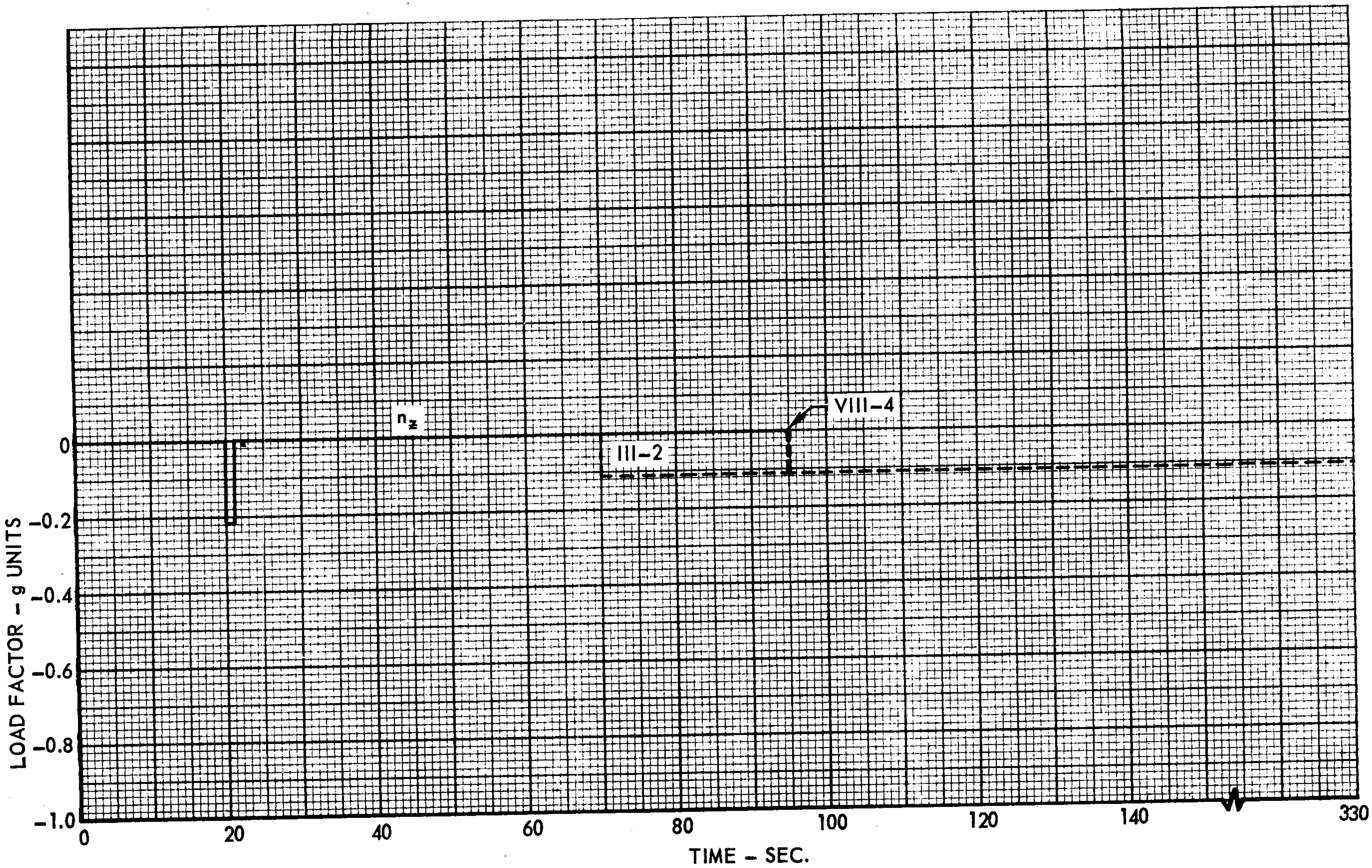

FIGURE 3-3 NORMAL ACCELERATION

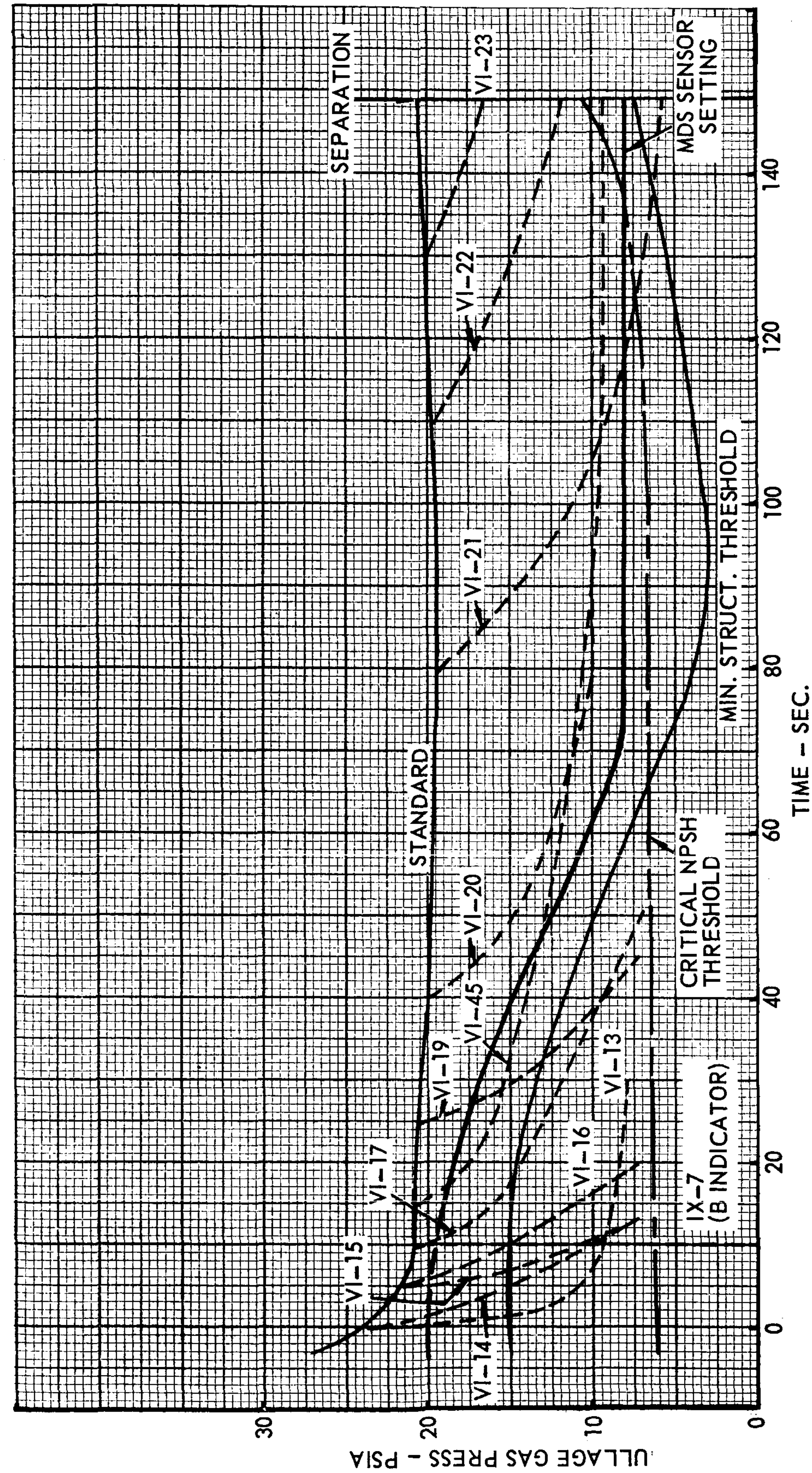

FIGURE 6-1 STAGE 1 FUEL TANK PRESSURE

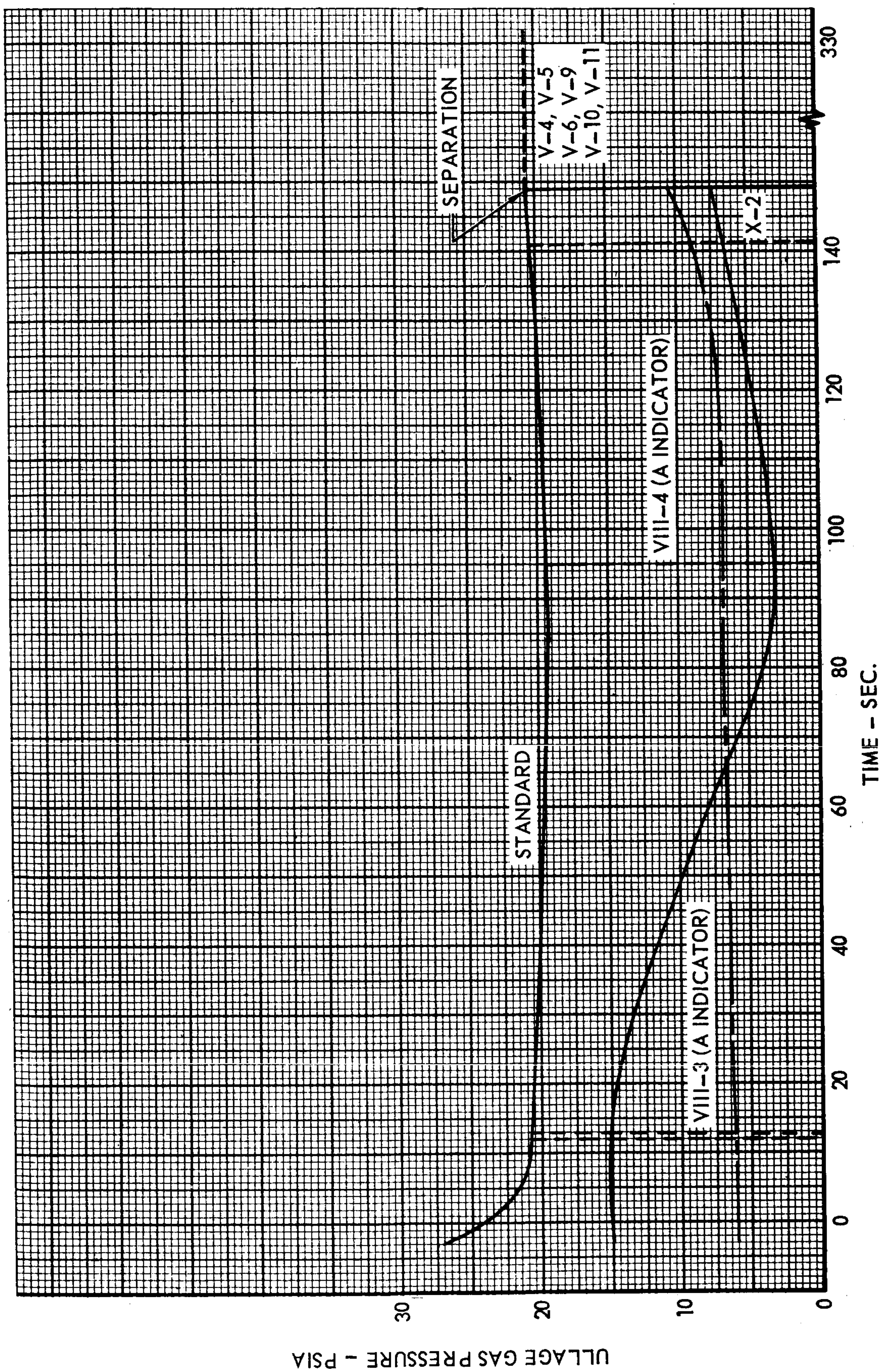

FIGURE 6-2 STAGE I FUEL TANK PRESSURE

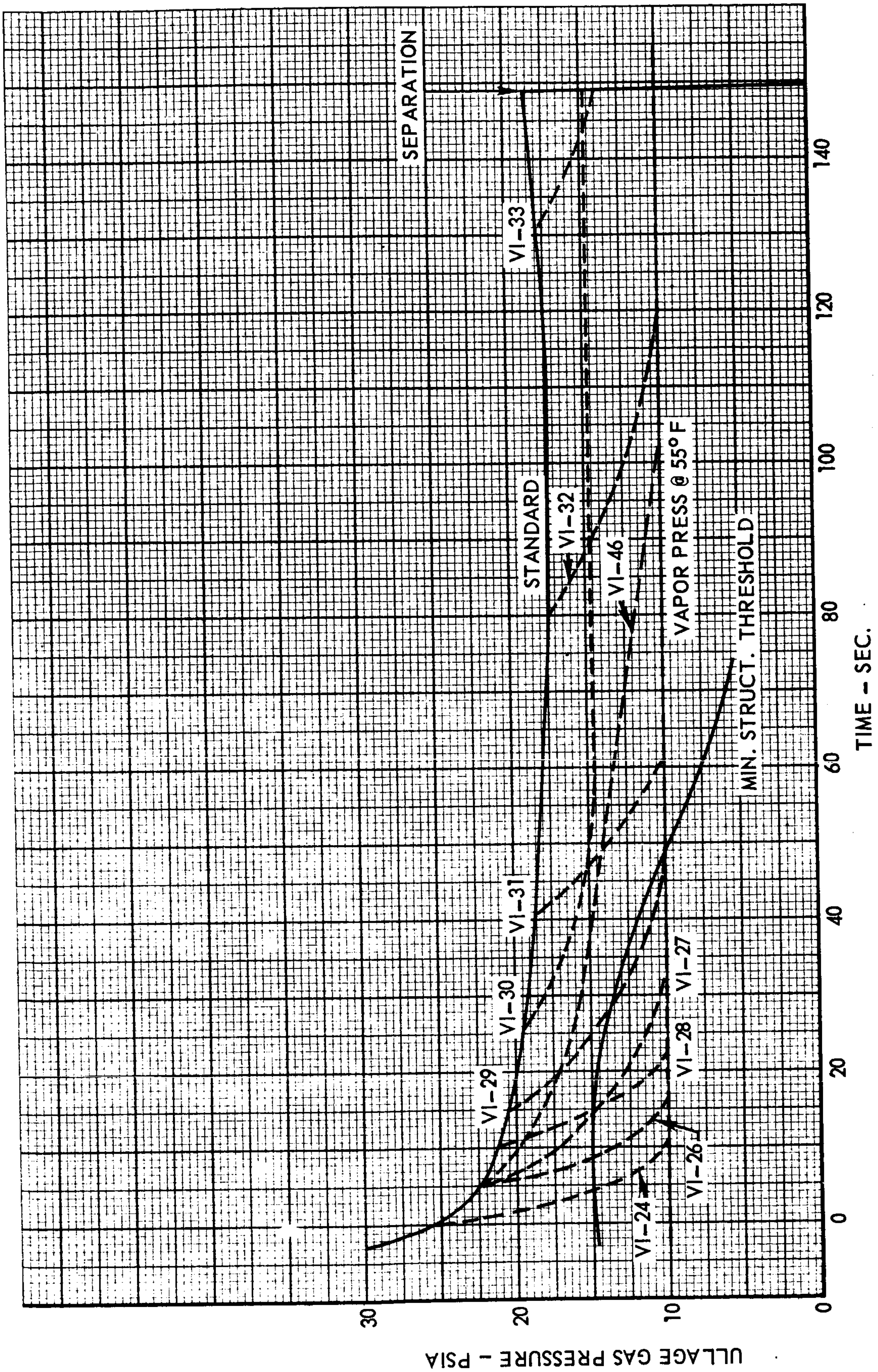

FIGURE 6-3 STAGE I OXIDIZER TANK PRESSURE

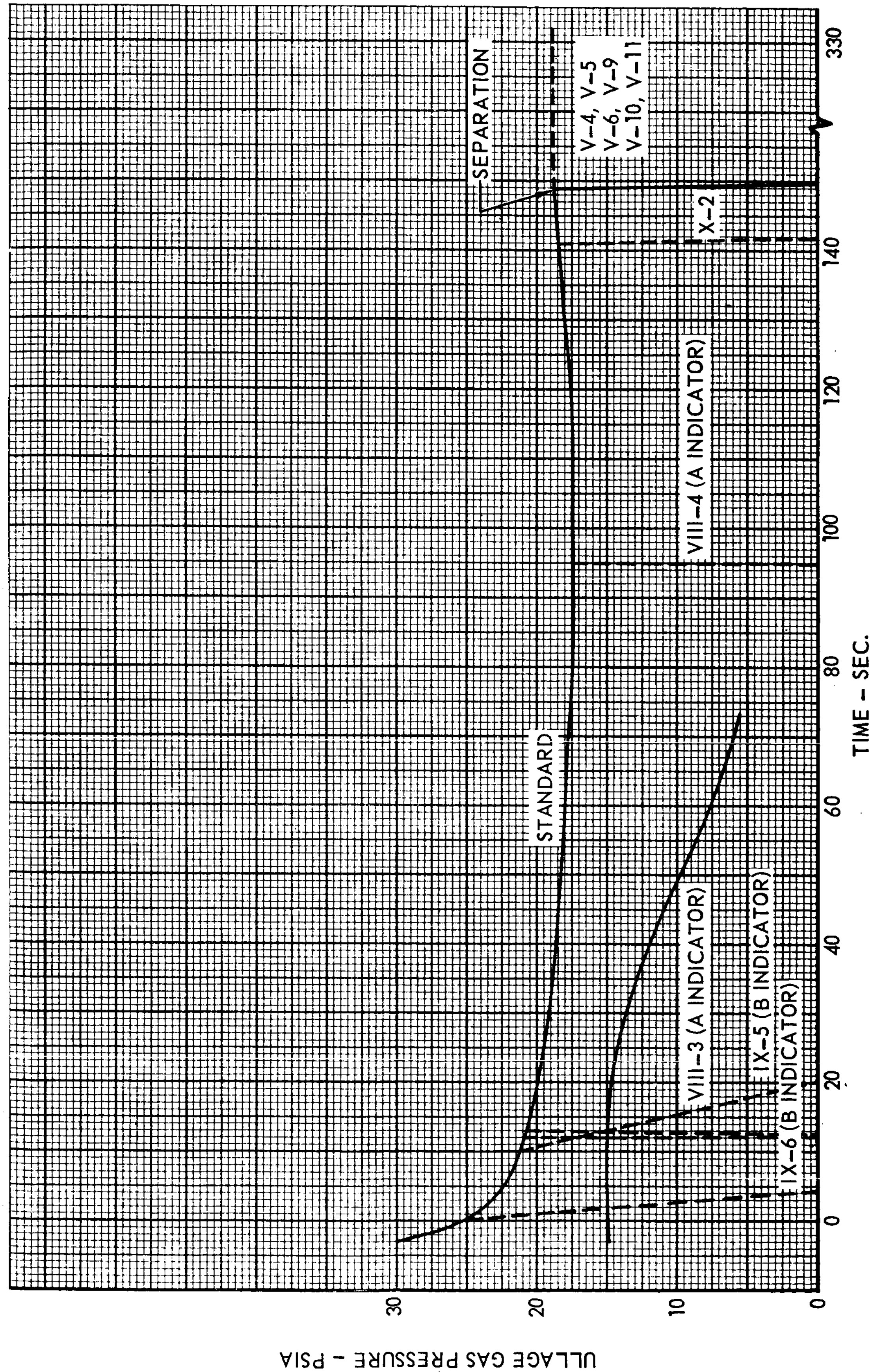

FIGURE 6-4 STAGE I OXIDIZER TANK PRESSURE

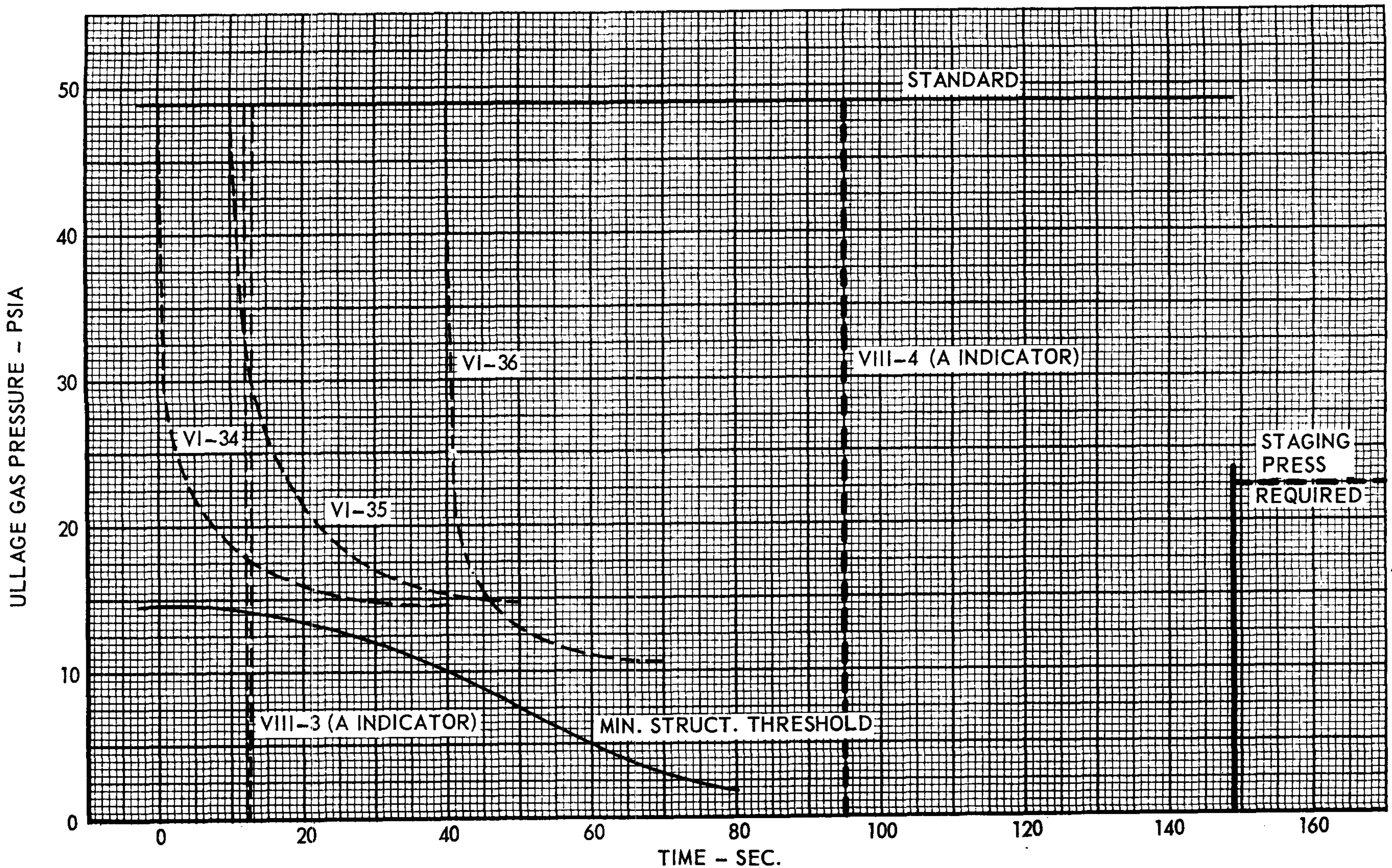

FIGURE 6-5 STAGE II FUEL TANK PRESSURE DURING STAGE I OPERATION

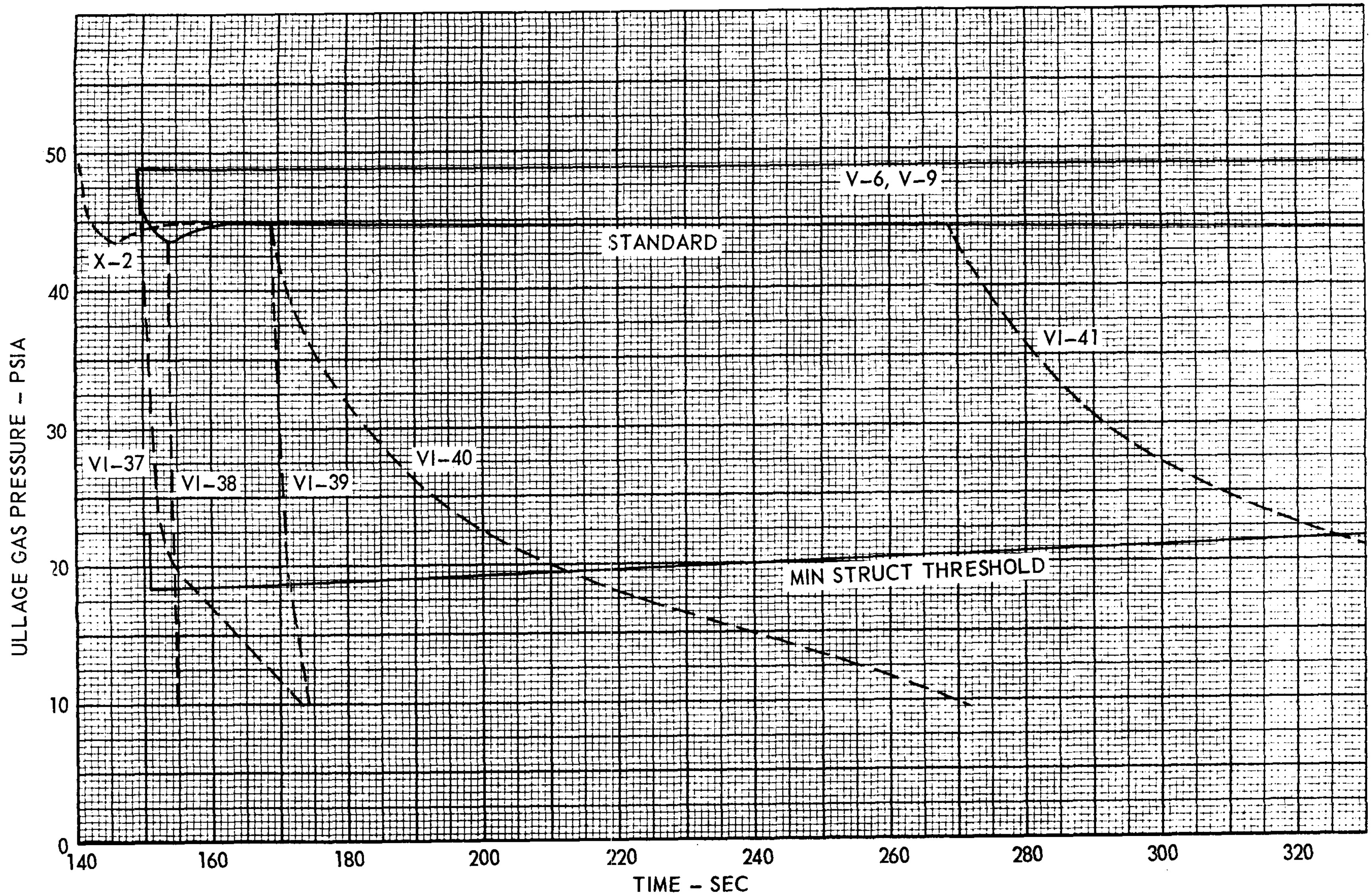

FIGURE 6–6 STAGE II FUEL TANK PRESSURE DURING STAGE II OPERATION

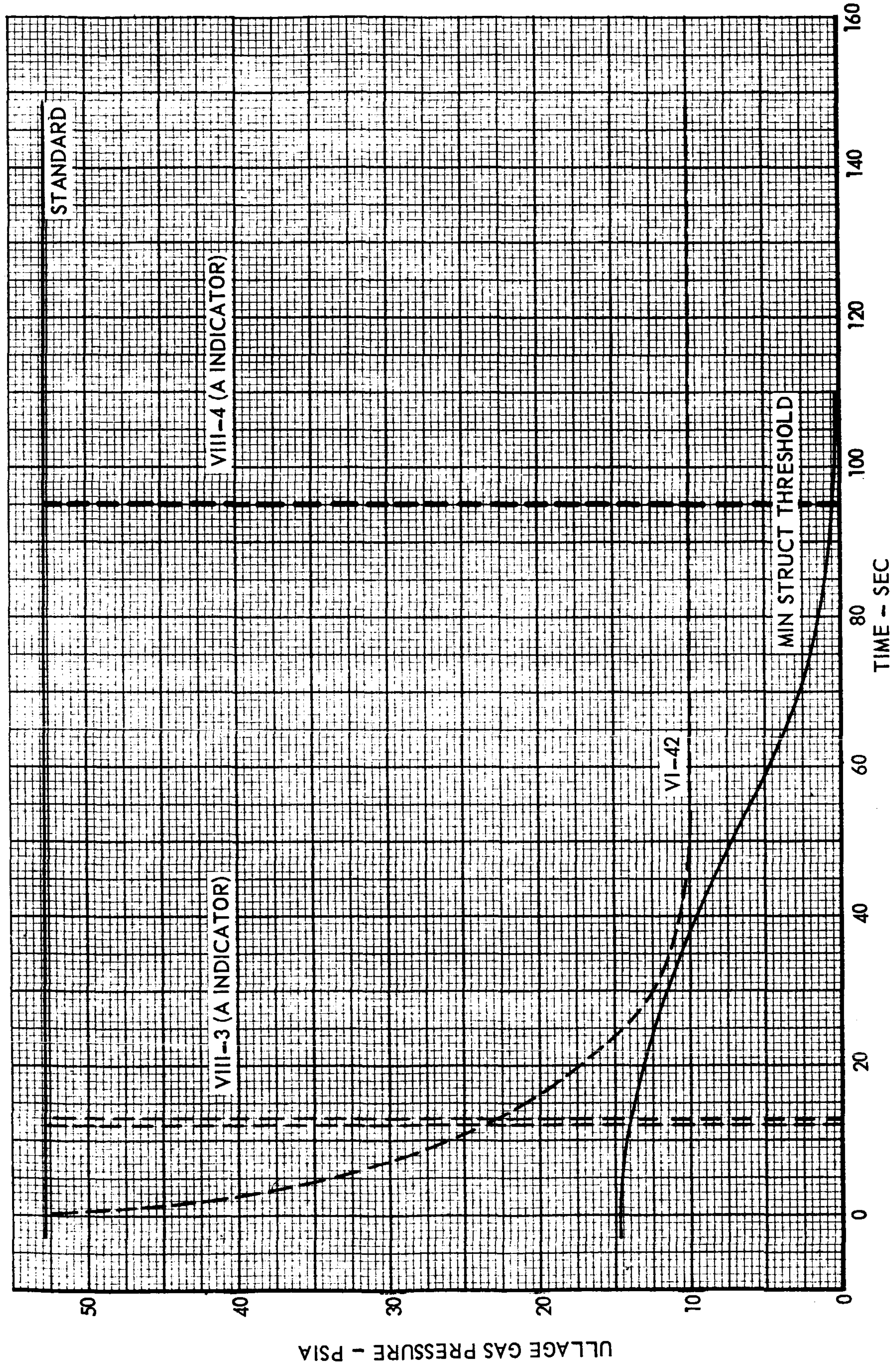

FIGURE 6-7 STAGE II OXIDIZER TANK PRESSURE DURING STAGE I OPERATION

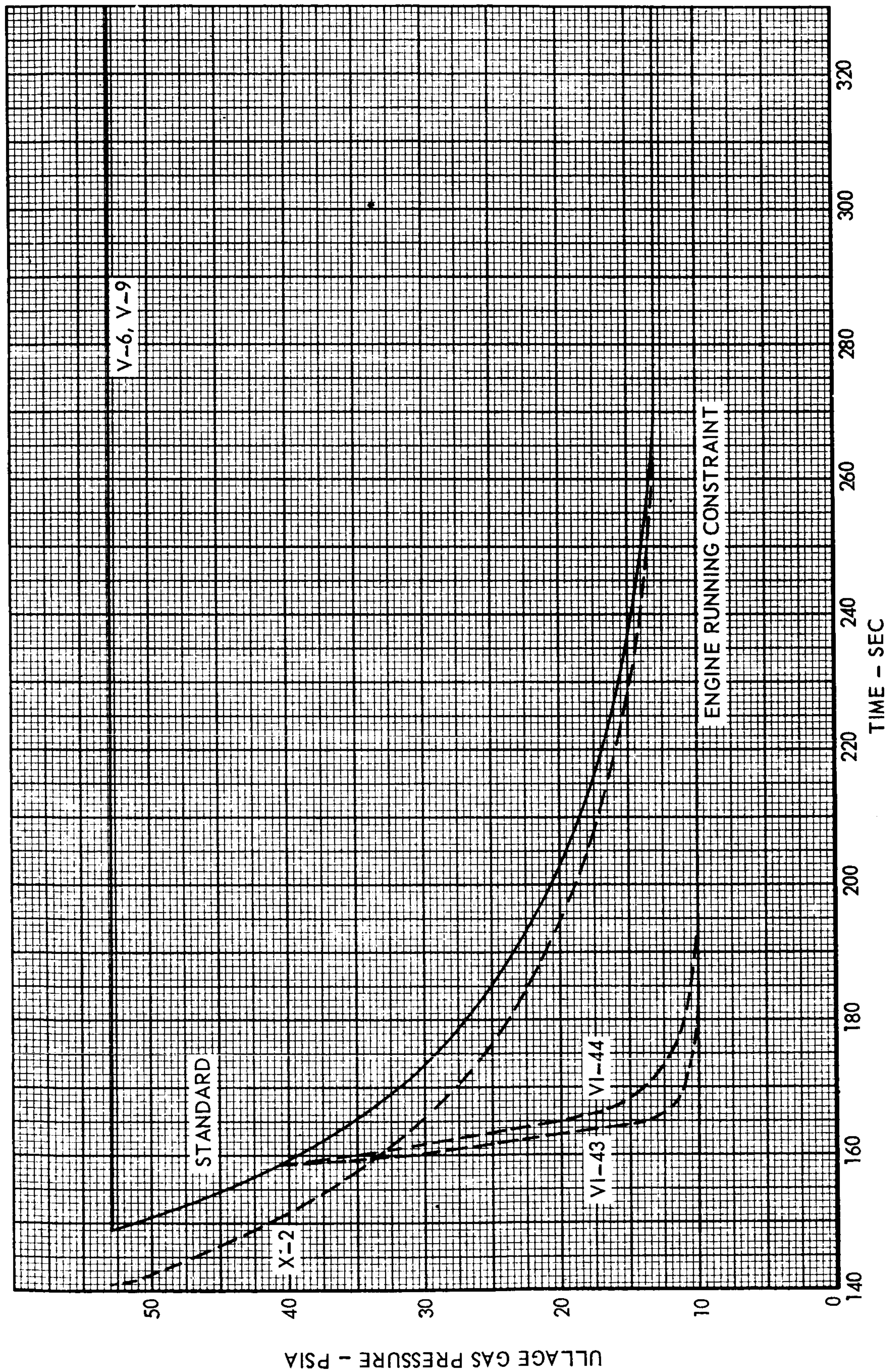

FIGURE 6-8 STAGE II OXIDIZER TANK PRESSURE DURING STAGE II OPERATION

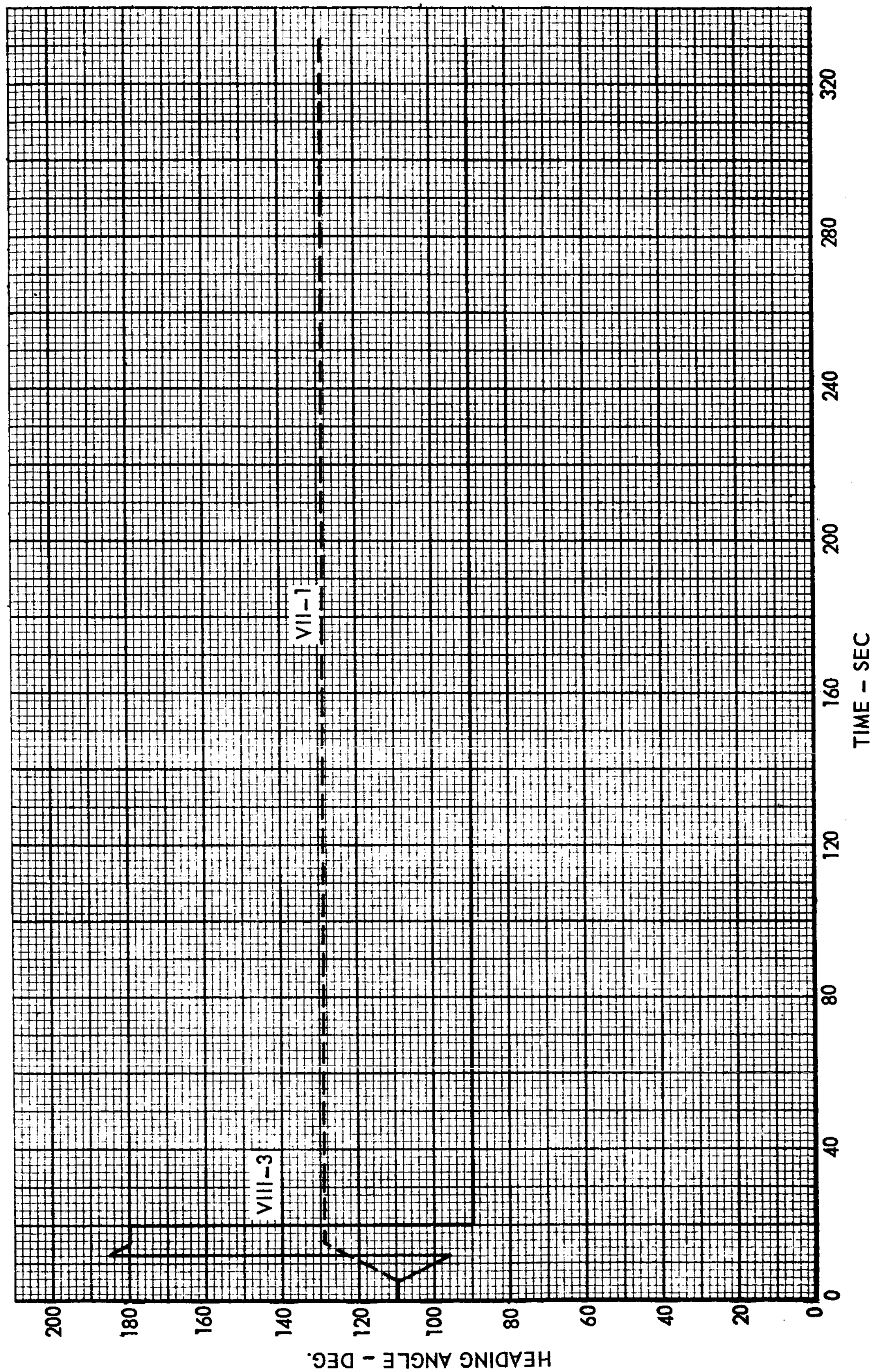

FIGURE 7-1 HEADING ANGLE

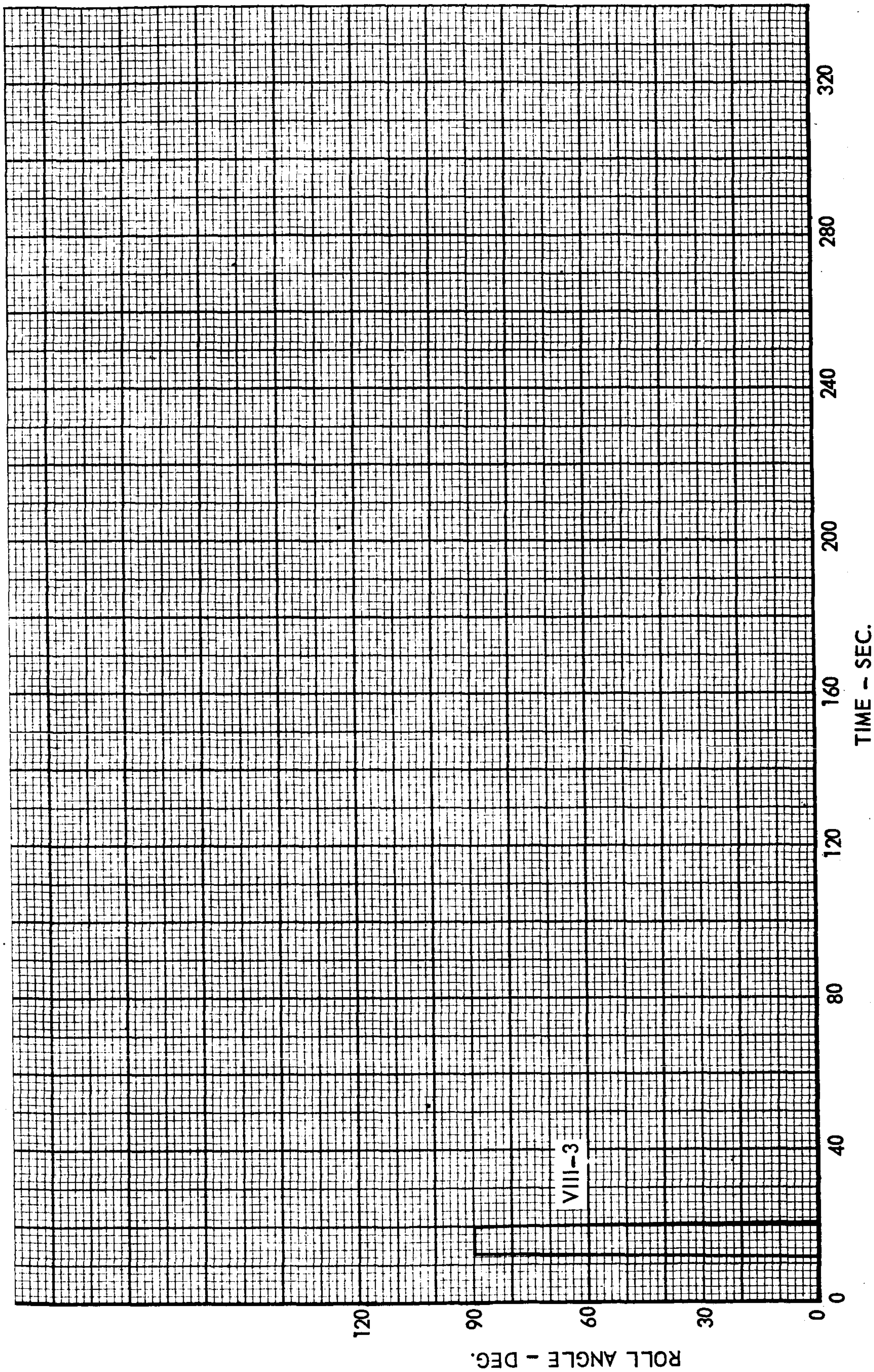

FIGURE 8-1 ROLL ANGLE

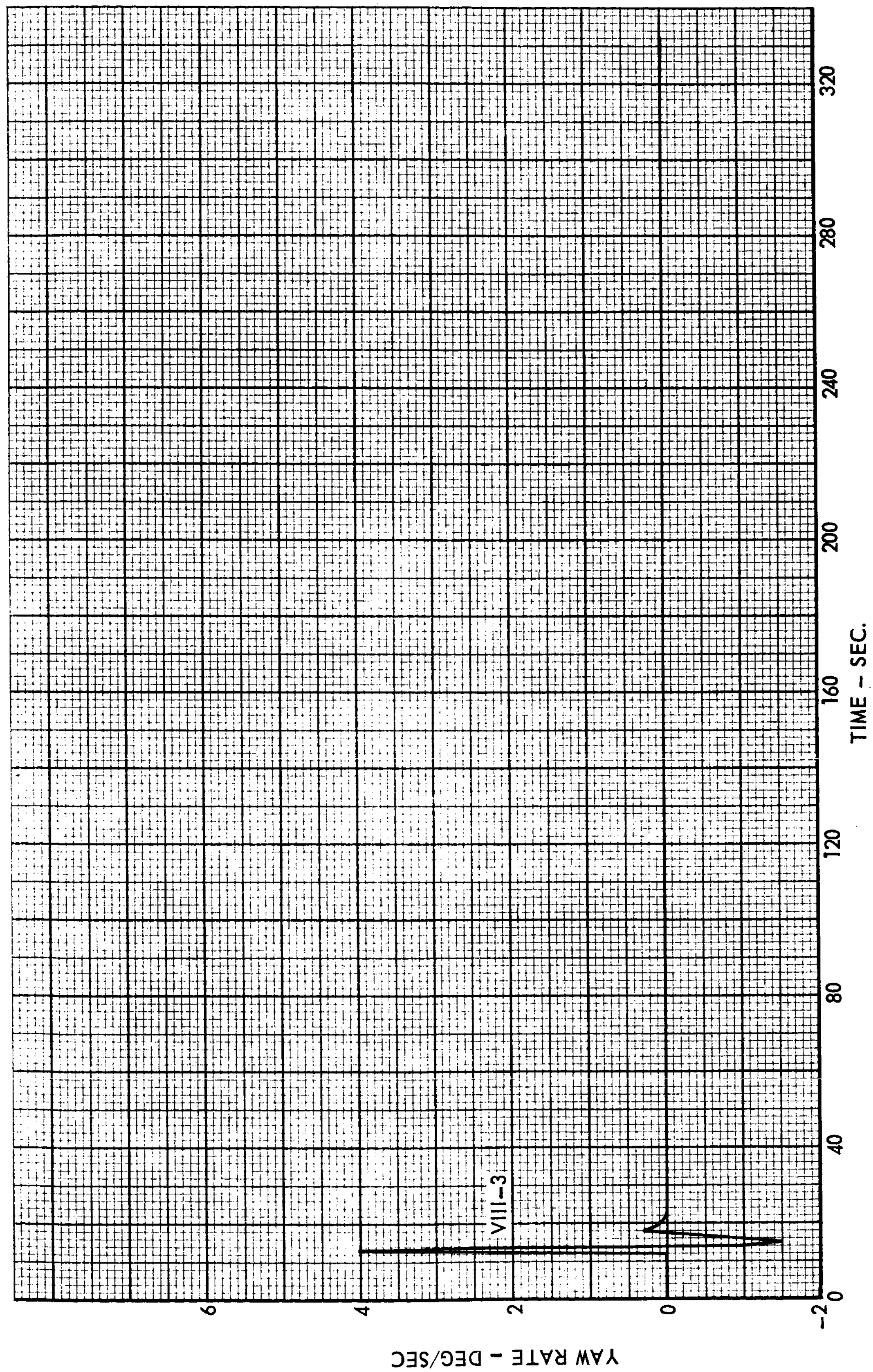

FIGURE 8-2 YAW RATE

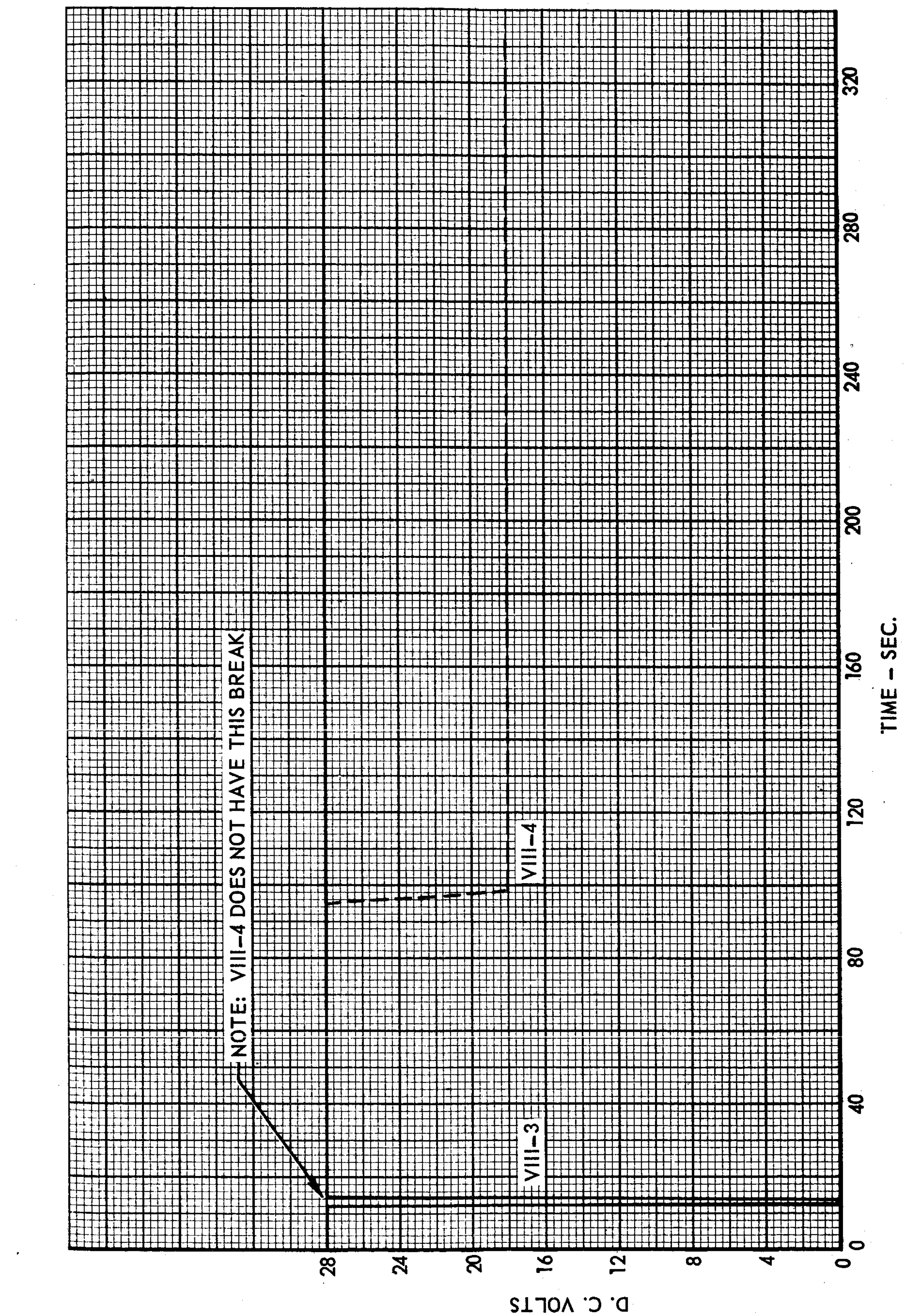

FIGURE 8-3 D. C. VOLTS

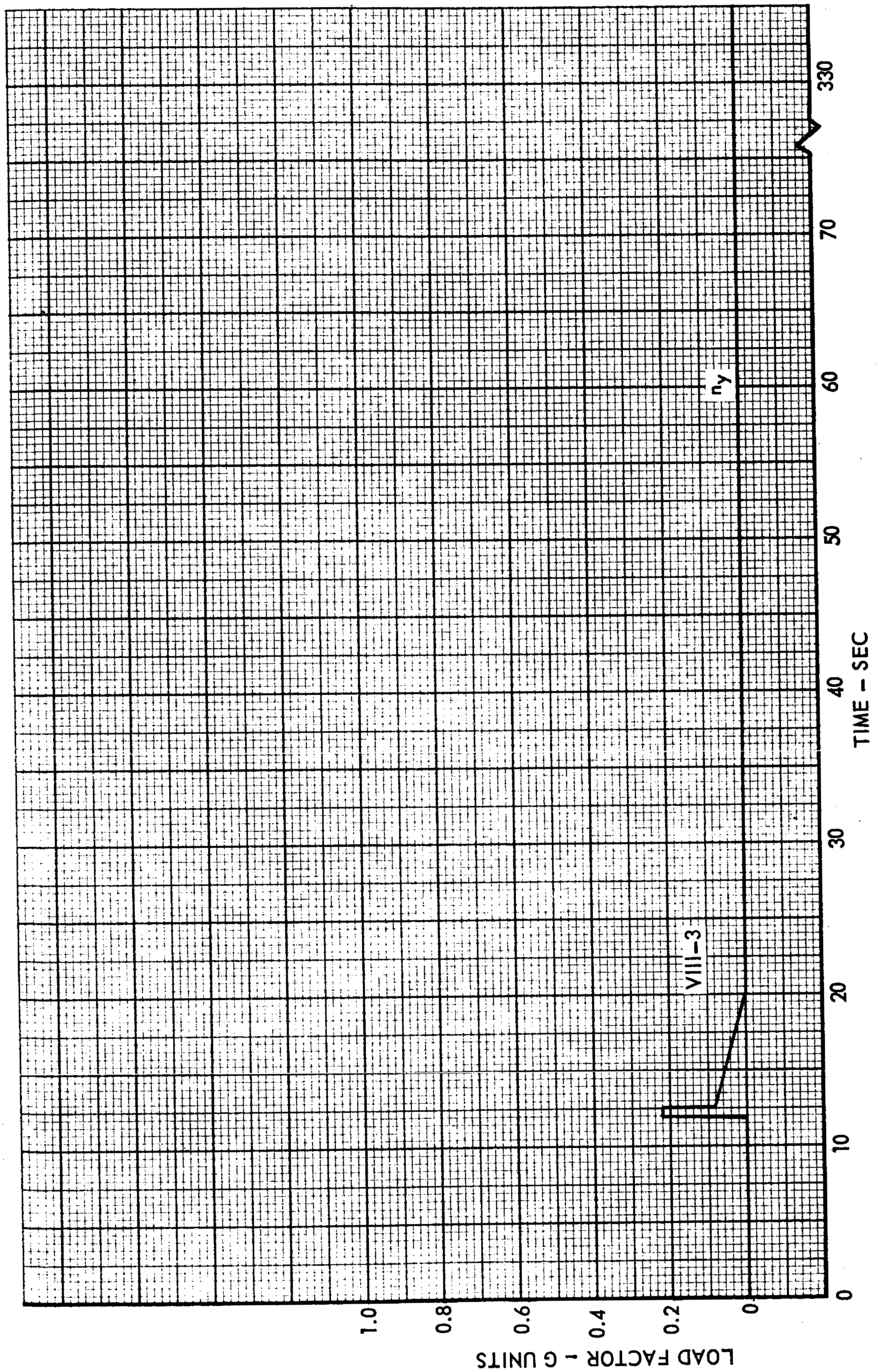

FIGURE 8–4 LATERAL ACCELERATION

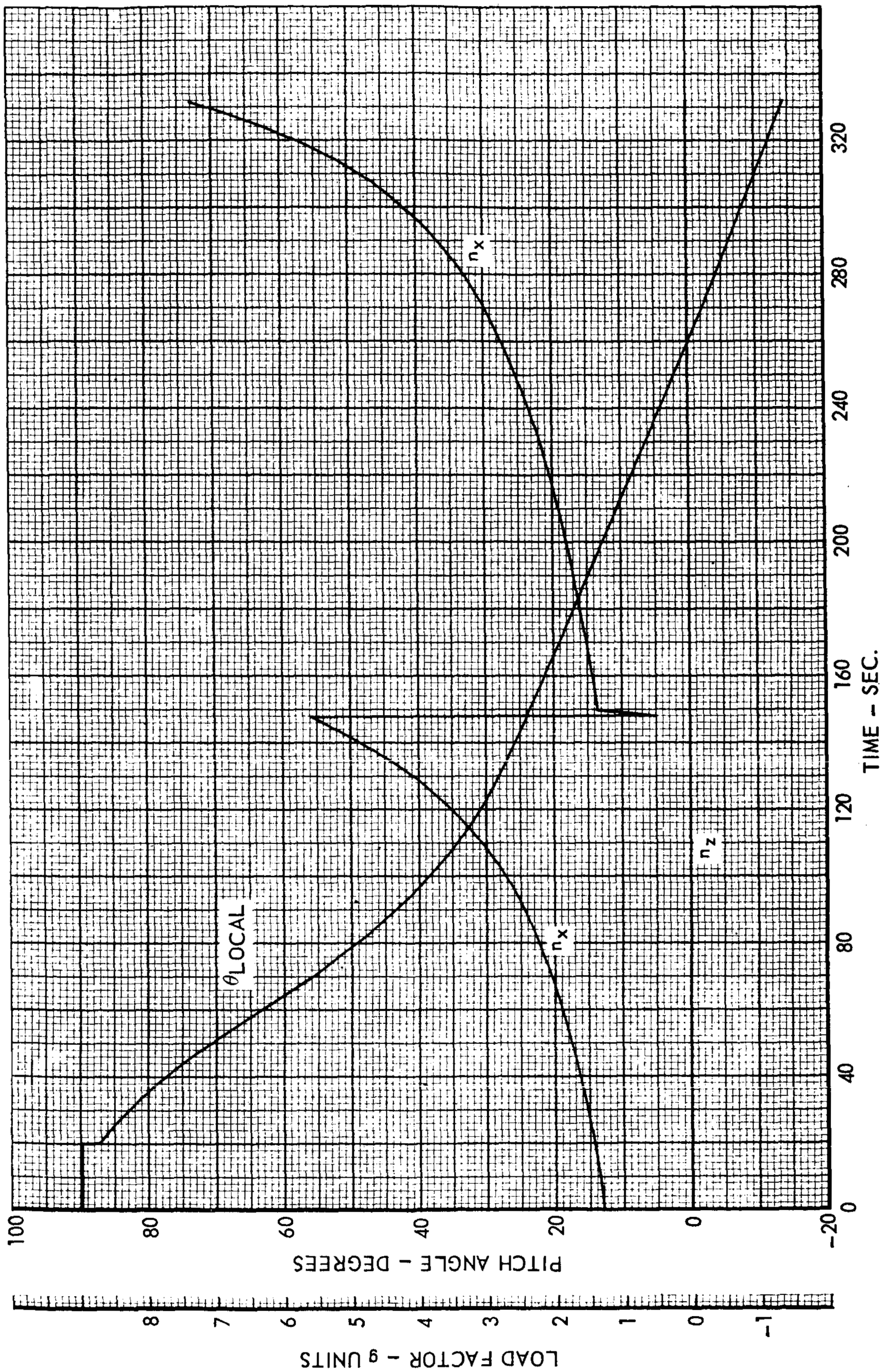

FIGURE 10-1 STANDARD DATA

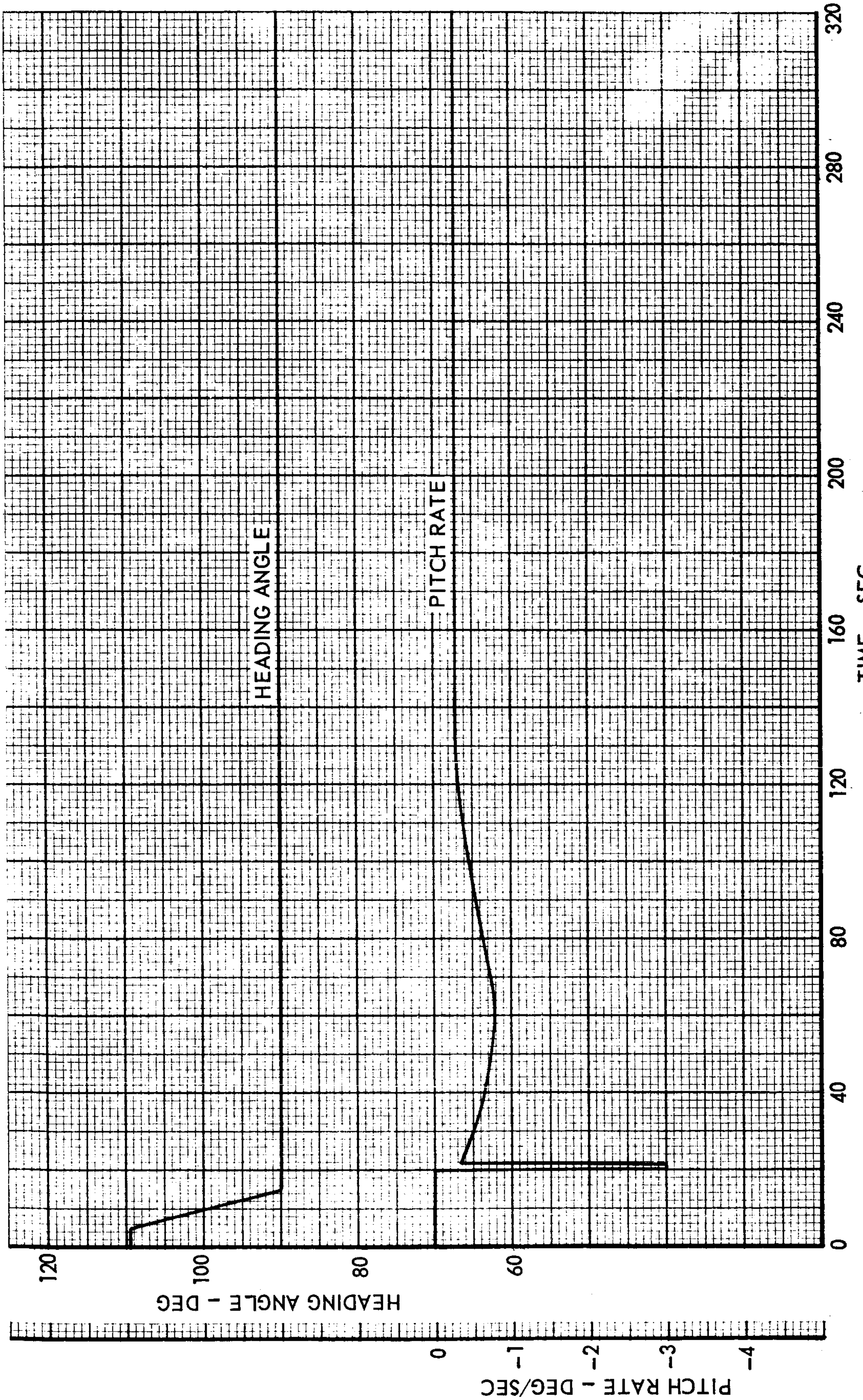

FIGURE 10-2 STANDARD DATA